NASA Technical Memorandum 85654

(NASA-TM-85654) STRUCTURAL RESPONSE OF TRANSPORT AIRPLANES IN CRASH SITUATIONS (NASA) 99 p HC A05/MF A01 CSCL 01C

N83-27980

Unclas
G3/05 28098

STRUCTURAL RESPONSE OF TRANSPORT AIRPLANES IN CRASH SITUATIONS

R. G. THOMSON AND C. CAIAFA

JUNE 1983

NASA
National Aeronautics and
Space Administration

Langley Research Center
Hampton, Virginia 23665

SUMMARY

This report highlights the results of contractural studies of transport accident data undertaken in a joint research program sponsored by the FAA and NASA. From these accident data studies it was concluded that the greatest potential for improved transport crashworthiness is in the reduction of fire related fatalities. Accident data pertaining to fuselage integrity, main landing gear collapse, fuel tank rupture, wing breaks, tearing of tank lower surfaces, and engine pod scrubbing are discussed. In those accidents where the energy absorbing protective capability of the fuselage structure is expended and the airplane experiences major structural damage, trauma caused fatalities are also discussed. The dynamic performance of current seat/restraint systems are examined but it is concluded that the accident data does not adequately define the relationship between occupant response and the dynamic interaction with the seat, floor and fuselage structure.

INTRODUCTION

Aviation Crash Dynamics Research has a history dating back to the early 1940's. During that period for the first time the idea of designing an aircraft for occupant survivability was given genuine consideration. Crashworthiness research was initiated by onsite investigation of aircraft accidents to identify those structural components and subsystems which contributed to occupant injuries and/or fatalities. Crashworthiness is the characteristic of a system which provides for survivability of occupants. The concepts of crashworthiness were further advanced through the research efforts of the National Advisory Committee for Aeronautics (NACA) (1,2), the Federal Aviation Administration (FAA) (3,4), and continued later by the National Aeronautics and Space Administration (NASA) (5-16). These efforts focused on both light- and transport airplane data in the areas of; (a). Post-Crash-Fire, (b). Fuel Containment, (c). Aircraft Component and Sub-System Behavior, (d). Crash Environment Data, and (e). ditching.

Within the past 15 years, (1965-1980) renewed efforts have been directed to improving the crashworthiness capability of aircraft. In the 1960's, the U.S. Army in an effort to reduce crash injuries and fatalities, investigated a number of helicopter aircraft accidents (17) identifying crash injuries and the injury causing mechanisms and embarking upon a substantial crashworthiness research program. These efforts culminated in the publication in 1967 of the Army's Crash Survival Design Guide (18). This guide is used as a tool by aircraft designers and manufacturers to incorporate crashworthiness design features into U.S. Army aircraft. The Army's efforts in crashworthiness have been extremely successful and rewarding. This success is directly attributable to a thorough evaluation of available accident data involving U.S. Army helicopter and fixed-wing aircraft.

For many years, the emphasis in aircraft accident investigation has been placed on determining the cause of the accident, with very little effort in identifying structural problems associated with crash survival. It is becoming apparent, through recognition of the U.S. Army success in helicopter crashworthiness, that safety in civil aviation can be further enhanced if crash survival improvements are incorporated during the initial phases of aircraft design. In January 1980, a NASA study contract was initiated with the three major transport aircraft manufacturers, Boeing Commercial Airplane Company, Lockheed-California Company, and McDonnell Douglas Corporation (refs. 19,20,21) to review and evaluate accident data and to:

(a). define a range of crash situations that might form the basis for developing improved crashworthiness design technology,

(b). identify structural components and aircraft systems that influence the crash dynamic behavior of an aircraft,

(c). define areas of research and identify approaches for improving crash survivability of transport aircraft,

(d). identify test techniques, test data, analytical methods, etc., needed to evaluate the crash dynamic response of transport aircraft.

Transport airplane travel is a relatively safe mode of transportation, accounting for less than 1 percent of the total transportation fatalities per year, and jet transport airplane performance in particular exhibits lower accident statistics than nonjets. Nevertheless, the introduction of the wide-body jumbo jet with its 300 to 400 passenger complement presents the potential for substantial loss of life or injuries in a single accident. Further the use of new advanced materials dictates that efforts continue in safety research to enhance occupant survivability in the event of a crash. With the continued technical advances in analytical predictive methods and experimental methods, many tools are becoming available for use by the airplane designer in addressing the crash response characteristics of future aircraft.

The purpose of this report is to delineate, from accident data, those structurally-related systems of transport aircraft that significantly participate in or influence the dynamic crash behavior of an aircraft and its occupants in a crash situation. While primarily concerned with occupant safety, the secondary benefits of crashworthy design concepts should not be overlooked. The necessity of considering crash safety in airplane design does not and should not, of itself, dictate increased costs. In the long run, designing for crash safety may prove to be cost effective in reducing operation and capital costs.

OBJECTIVE

The objective of the present study is to determine, with as much documented accident data as possible, the basic definition of representative crash scenarios experienced by transport airplanes in survivable or partially survivable accidents. Value limits of initial conditions observed for different classes of crash scenarios are discussed, and an approximate range of initial crash conditions is presented. To this end all available public transport accident data, as well as private transport manufacturers airplane data relevant to transport crash behavior, was reviewed and evaluated. In addition, aircraft structural components and subsystems were further identified and rated as to their participation in, or influence on, the crash dynamic behavior of a transport airplane and its occupants during a crash situation.

ESTABLISHMENT OF ACCIDENT STUDY BASE

Accident Data Summary

Many safety-related design changes and improvements in present day aircraft have as their foundation previous operational experience and accident data. Accident investigation has historically placed emphasis on determining the cause of the accident with little consideration being given to structural features that may influence or relate to injuries and/or fatalities. With this realization, a study was undertaken with the three leading transport manufacturers (refs. 19, 20, 21) to examine transport accident data to assess to the extent possible the behavior and participation of various structural subsystems during a crash. The material contained in the present paper is based almost entirely on the results of these studies, specifically centered on the following two tasks:

(a) To review and evaluate transport aircraft accident data, define a range of survivable crash conditions or crash scenarios that might form a basis for developing improved crashworthiness design technology

(b) To identify structural features and subsystems that influence injuries/fatalities in the crash scenario defined in (a).

The data base for this study began with a review of 933 worldwide jet transport accidents which occurred between the years 1959-1979 inclusive. Sources of this data were the files of the FAA/CAB, National Transportation Safety Board (NTSB), International Civil Aviation Organization, British Air Registration Board, Airline Pilots Association, and transport aircraft manufacturer's in addition reports in periodicals and newspaper and official accident reports released by foreign governments. Early reports (Circa 1960) contained, for the most part, sparse details on structural factors and the cause of occupant injury/fatalities. Later accident reports are more detailed particularly in the cases of those accidents investigated by the NTSB. These reports address not only the structural response but also human factors , define sequence of events, cause of injury/fatality, performance of cabin interior equipment, and factors affecting emergency egress.

The data base was evaluated with the intent of considering survivable structural accidents only. The following criteria were established for statistics to be considered in this data base:

(a) Airframe survivable volume was maintained during impact and prior to severe fire.

(b) At least one occupant did not die from trauma.

(c) Potential for egress was present.

(d) Accident demonstrated structural or system performance.

Criterion (b) is significantly more severe than the FAR criterion or NTSB definitions of a survivable accident. Criterion (b) does not mean that if one survives all should survive; rather, it means that one occupant was able to withstand the accident environment in his immediate vicinity. This permits accidents to be considered for research definition and direction that are beyond the scope of current design criteria.

Accidents in which the structural airframe played no significant role, such as flight turbulence accidents or maintenance personnel accidents on the ground, were disregarded in this study. Also disregarded were severe, nonsurvivable midair collision accidents. The exclusion of these accidents might alter statistics derived from the data base, consequently care is required in comparing the results of this study to studies using other data bases. Comparisons with other studies however, indicate that all "known" severe but potentially survivable accidents involving commercial jet transports have been included in the present study. All information contained in the present paper has been gleaned from references 19, 20, and 21, and these references should be consulted for further details concerning the accident data.

Aircraft Type

Airplane operating weight classes designated to assist in the evaluation of the accident data were: "Light", "Medium", "Heavy", and "Widebody". These weights are depicted in figure 1 (ref. 21) as classes B, C, D, and E. Weight class A represents all airplanes less than 12500 lbs (maximum takeoff) (the FAA designation of general aviation airplanes); weight class B "Light", 12500 - 100000 lbs ; weight class C "Medium", 100000 - 250000 lbs ; weight class D "Heavy", 250000 - 400000 lbs; and weight class E "Widebody", 400000 - 800000 lbs.

Table 1 (ref. 21) shows the breakdown, by airplane weight class and severity of injury (fatal, serious, minor) for the period 1964 to 1977 based on NTSB accident reporting in which non-structural accident types have been eliminated. The percentages shown in table 1 indicate that fatalities and serious injury accidents represent 18.5% and 12.3%, respectively, of the total. During this 14 year period only 5.0% of the accidents involved widebody aircraft. This low percentage is partially explained by the fact that the influence of these aircraft was not felt until the early 1970's.

In figure 1(b) the distribution of each type of aircraft in a weight class (ref. 22) currently being used in the worldwide commercial fleets are shown as well as the cumulative service years (i.e., number of aircraft multiplied by years in service, ref. 23). The medium weight class (C) accounts for 67 percent of the aircraft and 63 percent of the cumulative service years. The widebody aircraft (E) currently include 20 percent of the aircraft and less than 10 percent of the cumulative service years.

Table 2 (ref. 21) presents data which show the distribution of aircraft damage, postcrash fire, and primary accident types as a function of the severity of injury. For the structural-related accidents, the 63 fatal accidents are associated with 63 airplanes destroyed and 61 postcrash fires. There are a large number of accidents

(220, Table 2) in which aircraft experienced substantial damage and in which minor, or no, injuries occurred. This type of damage is usually local, such as in the landing gear region. From the bottom of the right hand column of table 3 (ref. 21) it can be observed from the structural-related accidents that of the 105(X,Y) accidents involving fatalities and/or serious injuries (63 + 42), 59% occur during landing, 19% occur during takeoff and 14% are associated with inflight accidents. Controlled and uncontrolled collisions with ground-water (table 3, I. A,B) acccunt for 67% of the inflight fatal accidents. Table 4 (ref. 21) show the distribution of accident types as a function of airplane weight class (fig. 1). Considering the number of different airplanes in each weight class there is relatively little accident data available for each particular airplane model.

Aircraft Size

Accident cases were categorized with respect to size as measured by operating weight in figure 1(A) (ref. 21). Weight classes B and C form a short haul light weight group up to 160000 lbs. A second, heavier, short haul group is formed from weight class C ranging from 160000 lbs to 250000 lbs. Weight class D forms a narrow body long haul group, while the heavier wide body aircraft over 400000 lbs long haul group, weight class E.

Referring to figure 2a each size group is represented in the data base. Smaller short haul aircraft constitute approximately 40% of the cases, larger short haul group approximately 20% of the cases, narrow body long haul group approximately 35% and wide body long haul aircraft approximately 5%. Of particular interest is the effect of size on aircraft crash performance and survivability. Considering the effects of scale as in dynamic modeling, it might be expected that larger aircraft would fare better than smaller aircraft if the crash environment is not scaled up. Further, the individual occupant does not scale up, but becomes relatively smaller in the larger aircraft with a corresponding improvement in survival prospects. For instance fuselage structural elements such as frames and stringers are stronger in an absolute sense and offer greater energy absorbing capability for larger commercial jet aircraft than for smaller propeller driven aircraft. This feature provides an inherent crashworthiness to the jet as compared to the propeller aircraft. A qualitative assessment of the accident data seems to indicate that relative size within the jet group has only minor effects on the crash performance of commercial jet transports. In general, it takes a larger tree, a larger house, and a deeper or wider ditch to do equivalent damage to a large aircraft. Since no two accidents are identical, an accurate comparison of damage between a large and small jet airframe cannot be made.

There is some indication that there may be an effect of size between some smaller propeller driven transport aircraft and the current jet fleet. Although not included in the study data base of ref. 21 three accidents were reviewed that involved high wing, propeller-driven aircraft of one generic type. In these accidents the seat response was different from that observed in survivable jet aircraft accidents in that many seats separated. Further there were instances of seat "stacking" in the forward fuselage and seat ejection on a large scale. These propeller driven aircraft, because of their smaller dimensional and structural arrangement, may present a smaller mass ratio of airframe to seats than do the larger jet aircraft. This situation may account for the different seat crash response seen by the two types of aircraft.

Aircraft Configuration

Accident cases were categorized with respect to configuration in figure 2b (ref. 21). Emphasis was placed on differences between aircraft types and service uses. The aircraft fuselage internal configuration was classified according to type of service, i.e., passenger or non-passenger. Also in the internal fuselage configuration is the presence of body fuel cells and body fuel lines. The external configuration differences are related to fuselage width, engine placement, landing gear, and fuel cells.

By referring to figure 2b, approximately 20% of transport airplane accidents involve non-passenger service. Non-passenger service was further divided into cargo, training, and positioning flights. As regards cargo service, a review of the accident data shows some cases where cargo shift during the accident increased the hazard to the flight crew. (A notable instance is an accident where cattle pens broke loose during an overrun and blocked the cockpit door). Training accidents most frequently involve engine-out takeoff attempts. These accidents involve extreme yaw and roll angles with ground strikes of wings, engines or aft fuselage. Some accidents involve touch-and-go landing practice.

The principle variation in structural configuration is in placement of engines. Approximately 60% of the accidents involve aircraft with wing mounted engines and 37% involve aft mounted engines while 3% involve wing and aft body mounted engines. The aft mounted engines only separated from the aircraft due to high acceleration loading, while the wing/pylon mounted engines separated both from high accelerations and from contact with external objects. The Comet IV has engines mounted internally in the wings which help to contain the engines in a crash.

In figure 2c it may be seen that engine separation occurred in 55%, landing gear collapse or separation occurred in 75%, wing box breaks occurred in 45%, fuselage breaks occurred in 48%, and water ditching impact breakup occurred in 3% of the accidents. The separation of an engine and the breaking of a wing box imply fuel spills. In some instances a fuselage break in an aircraft with aft mounted engines also caused a fuel spill. The wide body long haul aircraft have main body landing gear that transfer high impact loads to the fuselage structure. Water ditching impact breakup is considered separately from fuselage breaks because in general the forces involved are different.

In figure 2d engine placement was observed to affect the fire hazard. In particular, aft body location is associated with the breaking of engine fuel lines and body fuel lines. Wing pylon mounted location had, in addition to fuel line breaks, the rupturing of wing fuel tanks due to pylon/engine separation. The engines mounted internally in the wings with wing pod fuel cell tanks exhibit engine fires. The wing pod cell tanks have separated due to high accelerations and have contacted external objects. The associated fire hazard was tank rupture.

Containment of fuel, spread/scatter of fuel, and ignition of fuel constitute major areas of study for improving survivability in jet transport accidents. Ignition sources are usually present in aircraft crashes. Hot sections of engines provide an ignition source and landing gear failure usually produce showers of sparks due to friction of structure rubbing the ground. Electrical arcing may occur when the electrical compartment is penetrated or when electric wiring is severed as in the instance of engine/pylon separation.

Operation Phase

The percentage of accidents by operational phase and by operational time is shown in figure 3 (ref. 19). Considering those operational phases taking place near or on the ground (Load, Taxi, Takeoff, Initial climb, Initial Approach, Final Approach, Landing), 79.3% of the accidents occur in 18% of the operational time. Further, those accidents that occur during climb, cruise, and descent are generally non-survivable and outside the range of this crash dynamics study.

The average distance from the airport that the various accident types occur is shown in table 5. In figure 4 a normalized fatality ratio (ref. 21) is plotted as a function of distance from the airport in miles. The Fatality Ratio (FR) is the ratio of number of fatalities/ total number of passengers onboard and a normalized fatality ratio is obtained by dividing by the average fatality ratio, based on the total number of reports and briefs considered. This average fatality ratio was 0.1917 (ref. 21), and an "average" accident would have a normalized fatality ratio equal to one. Normalized ratios above one and below one are more and less severe, respectively, than the 'average'. The fatality ratio is related to the distance from airports at which aircraft accidents occur. Accidents around airports such as "Hard Landings", "Takeoff Aborts", and "Overshoots" are relatively fatality free. Under- shoots which occur at approach velocities but involve terrain with some degree of roughness and contour unpredictability at an average distance of approximately 900 feet shy of the runway, are moderately severe, but less than the average. Stalls, which occur on an average about 1.2 miles from the airport, are severe accidents. The airplane's uncontrolled attitude at impact during a stall contributes to this severity. Collision with Obstacles at or near the airport are relatively mild. Usually they involve wires and approach lights which damage the airplane but do not inhibit the pilot from making a safe landing. Injuries that result from this type of accident often occur during the evacuation from the airplane. Collisions with Obstacles, generally trees and buildings, are more fatal than the average. This type of accident occurs on an average 2.3 miles from the airport and has a fatality ratio equal to 1.86. Uncontrolled Ground/Water Collisions occur on an average 2.7 miles from the airport and have a fatality ratio of 3.26. The Uncontrolled Ground/Water Collision accident type occurs at an average distance of 8 miles from the airport and has a normalized fatality ratio of 3.59, which is the highest of all the categories.

Table 6 shows a distribution of accident occurrence in the proximity of airports. Based on a total of 441 accidents involving 455 aircraft (eight of the 455 aircraft were other than air carrier aircraft) resulting in 447 accident reports in the NTSB accident summary for 1964-69, approximately 50 percent of the accidents occurred at the airport. However, these 50 percent account for only 17.6 percent and 21.7 percent, respectively, of the accidents classified as fatal or severe injury. The nearly 36 percent of the accidents that occur at distances of five miles or more from the airport account for 50 percent and 67 percent of the fatal and serious injury accidents, respectively. The large number of fatal and serious injuries associated with accidents which occur 5 or more miles from an airport attest to the facts that extremely high impact conditions coupled with obstacles, uneven terrain, and inaccessibility of fire-fighting equipment and personnel, all play a role. In addition, these accidents may be characterized by a lack of pilot control to minimize the severity of the crash. For these reasons it appears that the primary emphasis of accident scenario studies should be accidents in the vicinity of airports and generally associated with the landing or takeoff phase of operation.

Validation of Data Base

The NTSB accident data was used as a basis for formulating accident scenarios primarily because it provided the most details about accidents. The NTSB data represents less than 29 percent of the total accidents in the world during the period 1964-77. During this period of time the NTSB summaries include 783 accidents compared to 2707 worldwide accidents (reference 24). Figure 5 (ref. 21) shows a comparison of the number of occurrences of fatal, serious injury and minor/noninjurious accidents for both the original set of data (783) and the reduced (structural-related) set (341) as a function of primary accident types. The distribution and severity of injury exhibited by both sets of data are similar.

Since the primary emphasis of this study is long-range future aircraft with responsibility to perform in compliance with FAR25 requirements, the validity of using NTSB data has to be established. In an attempt to do this the worldwide accident summaries were reviewed on the same basis as the NTSB data as shown in Table 7. The summaries provided in reference 24 were often sketchy and presented difficulties in establishing accident categories associated with many accidents. Thus, the task of summarizing this data was not straightforward. Working within these constraints and limiting the review to class B, C, D, and E airplanes, a total of 660 worldwide accidents are summarized in Table 7 as was done in Table 4 for the NTSB data. The worldwide data is for the period of 1964-1979 and does not include the accidents in the NTSB data file. Since "System Malfunction" and "Collisions with Obstacles" often result in secondary accident conditions a comparison of the two data sets on the basis of accidents in which the impact conditions are more clearly defined is presented. A comparison of the two sets of data show the associated percentages are as follows:

	FATAL	SERIOUS	MINOR/NONE
NTSB	20%	9.3%	70.7%
WORLDWIDE	20%	7%	73%

The use of NTSB data upon which to formulate crash scenarios is considered adequate since the data 1) is representative of the accident history; 2) more readily available; and, 3) consistent with the trends associated with modern day jet usage.

Table 7 shows a comparison of the worldwide data versus the reduced NTSB summary for severity of injury versus accident type. While percentage distribution varies somewhat for each accident type the trend of the data is consistent. For example, air to ground type accidents such as controlled and uncontrolled collisions, stall, collision with obstacles and undershoot, still show the highest percentage of fatal accidents. Air to ground type accidents such as hard landing, wheels-up or retracted gear show little or no fatality occurrence for both sets of data. The worldwide data shows a higher percentage of fatal accident occurrence for an undershoot accident and lower percentage of fatal accident occurrence for an overshoot occurrence than does the NTSB data. A ground-to-ground accident such as an overshoot, or swerve, fatality occurrence shows percentages of from 3 percent to 9 percent. Fatal accidents as a result of gear collapse which occurs during landing, takeoff and taxi, presumably at low speed, occur less than 5 percent of the time. Undershoot accidents, which show a fatality accident percentage which varies from 16 percent to 38 percent, are a cross between a hard landing and air-to-ground collision. The spread in fatal accident percentage for this type accident may be associated with the proximity to the airport at which this accident occurs.

Summary of the Selected Accident Study Data Base

The purpose of the selected accident study data base was to review the historical accident data to identify and define aircraft behavior and structural break-up and the associated injury causing mechanisms or factors. In an objective, but somewhat unavoidably subjective manner, a combined total of 176 fairly-well documented survivable accidents were chosen to form a data base from the total (341) examined in references 19, 20, and 21. A listing of these 176 accidents are given in Table 8. This data base was then used to study and assess the pertinent structural behavior of both the total airplane and selected subsystems. In a few isolated cases the one survivor condition for survivability was waived when it was felt that trauma forces were within human tolerance levels, but a fire hazard existed. The distribution of accident data between the three contractors (refs. 19, 20, and 21) is illustrated in figure 6. The three transport manufacturers generally examined different accidents, but some accidents were examined by all three manufacturers as indicated in the figure by the cross-hatched area, some by two of the three as indicated by the hatched areas, and other accidents solely by one manufacturer (primarily the accidents involving his aircraft). It should be noted that accidents in the data base are "potentially impact-survivable" due to the inherent structural capability of the airframe.

A summary of the selected accident study data base from ref. 1? only is presented in Table 9. A listing of these 153 well-documen accident cases are given in Table 10. The accident data base co 133 cases involving hull loss and 20 cases involving substantial . There are 103 cases in which fire was present. In 95 of these ca aircraft suffered a hull loss and in the others the aircraft su substantial damage. In addition there were 22 accidents in which a fu spill occurred but for which there was no fire. Some of these involved situations where the aircraft came to rest in water or where the climatic conditions such as low temperature precluded the vaporization of fuel or where terrain drained the fuel away from the aircraft; but for these circumstances those cases might also involve fire casualties or further aircraft damage.

The data base contains 119 (or 78% of the 153)accidents which involve fatalities and/or serious injury. For this study the NTSB definitions have been extended further to identify the cause of the fatality/injury. Trauma is taken to mean that the fatality/injury is caused by mechanical forces such as inertia forces resulting from high accelerations or from impact with the surrounding structure. Fire/smoke is assigned to those fatalities/injuries that result from burns, or inhalation of hot gases, smoke or noxious fumes. In some cases passengers are presumed to have received trauma injuries that prevented or slowed down their egress and as a result they died of smoke or flames. For those accidents where the aircraft stopped in water, fatalities due to drowning are identified. No attempt has been made to identify injuries (chemical burns) due to contact with raw fuel although some instances have occurred. Referring to Table 9, it may be seen that approximately 35% of the accidents involve fatalities due to trauma, 37% involve fire/smoke, and 6% involve drowning. As regards the serious injuries 60% involve trauma, and 30% involve fire/smoke. It should be noted that some accidents may involve combinations of the above causes of injury. The selected cases have attempted to address the serious but survivable accident; however, four special cases are included in this data base. The first special case is a 707 at London in 1968 where the aircraft caught fire on take off and made a successful landing but 5 deaths due to fire occurred during evacuation. The second special case is a DC-8 at Toronto in 1970 where the aircraft was damaged during an attempted landing and exploded during the subsequent attempted go-around killing the 108 occupants. The third special case is a DC-9 at Boston in 1973 where the aircraft struck a seawall, broke-up and burned; one passenger walked out of the fire but died within 24 hours. The fourth special case is a 737 Madras accident in 1979 in which the detonation of an explosive device in the forward lavatory led to landing conditions that resulted in an overrun.

DEFINITION OF ACCIDENT CATEGORIES AND THEIR RELATION TO FATALITIES

Probable Cause of Accidents

The probable cause of accidents is presented in figure 7 (ref. 19). "Probable cause" is based on the determination of the accident investigation team. For 13 accidents the cause is unknown. For 140 cases where cause has been determined 76.4% of the cases are attributed to the cockpit crew, 11.1% to the airplane, 5% to weather, 2.1% to the airport/air traffic controller, 1.4% to miscellaneous, 0.7% to maintenance, and 0.7% to sabotage.

The aircraft was the cause of the accident in 11% of the cases. Landing gear systems and support structure were involved in 7 accidents. Failures involved brakes, wheels, tires, and structure. Engine disintegration, thrust loss, and thrust reversers were involved in 6 accidents. Flight instrumentation was involved in 2 accidents and ground spoilers and elevator trim tab were each involved in 1 accident. From these data it may be concluded that a large percentage of the accidents can be attributed to human error such as pilot and ground control assistance. Such items as ground proximity warning, wind shear detection, automated landing and navigation systems, and advanced integrated systems for pilot assistance offer the best hope for eliminating most accidents in the "avoidable" category. Improved ground control and reduction of hazards on and around airports is another area for improved safety. The avoidance of collisions between aircraft and with ground vehicles should be attainable. Reduction of hazards such as drainage ditches, poles, trees, columns, outbuildings and birds from airports is a matter of concern. In addition the overrun areas for runways could be improved to reduce the severity of accidents in these areas.

Accident Severity and Survivability

In a combined study of foreign and domestic (U.S. and possessions) accidents involving the combined total of selected survivable accidents in refs. 19, 20, and 21, 98 domestic and 78 foreign accidents were reviewed. A listing of these 176 accidents are given in Table 8. These accidents contain the 91 domestic and 62 foreign accidents shown in Table 9. In figure 8 the domestic and foreign accidents are compared on the basis of percent fatalities to total occupants on board for "Phase of Operation", figure 8(a), and "Fatality Category" figure 8(b). The domestic accidents in the fatality category 8(b) show a ratio of trauma - to-fire fatalities of 1.5 while the foreign accidents show a reverse ratio of fire-to-trauma fatalities of approximately 2. These differences are also apparent in figure 9 in which the "Failure Mode", figure 9(a), and, "Accidents with Fire and Fatalities", figure 9(b), are shown plotted versus percentage of accidents. Figure 9(a) has a higher tank rupture for foreign than domestic accidents, and figure 9(b) indicates a general increase in fire and fire fatalities for the foreign accident data when compared to domestic. These differences may reflect the lack of documentation on trauma-related fatalities in the foreign data or may indicate a real trend of an increased fire hazard in foreign accidents.

Accidents have been assessed on the basis of amount of damage to the aircraft and the effect of this damage on survivability. Structural damage severity in accidents contained in the data base (ref. 19) were assembled into 6 categories as shown in table 11. In general the degree of structural damage and the energy to be dissipated increases as the category increases. Categories 1 through 3 involve accidents in which the occupant protective shell is generally maintained and the fuel system is not destroyed. At category 4, major fuel spillage is introduced. Three classes of fuselage break are used to distinguish the severity of the accident. A class 1 break has the fuselage broken with fuselage sections essentially remaining together. The opening allows fuel/fire entry but is too small for occupant egress. In class 2 breaks the fuselage separates sufficiently to allow occupant egress and fuel/fire entry, but the sections maintain proximity to one another. Class 3 breaks have fuselage sections which separate and come to rest at some distance from each other. Category 3 accidents are severe accidents involving either severe lower fuselage crush or class 1 or 2 breaks, or both. However, in category 3 there are no major fuel spills. Categories 5 and 6 involve increasingly severe destruction of the aircraft with serious breaks in fuel tankage.

The 153 well-documented accidents in the data base have been grouped by category and are summarized in table 12 and figure 10, from which some general observations may be made. First as regards overall survivability, fire presents the greatest hazard. Known fire fatalities outnumber known trauma fatalities by 2.8:1. (This is in contrast to the results presented in figure 8(b) for domestic accident data only.) The foreign accident data reflects the same fire to trauma fatality ratio (approximately) as given here. Fire hazard is most severe for accidents having major fuel spills due to rupturing of fuel tankage (categories 4, 5, and 6). Trauma fatalities occur mostly in categories 5 and 6 which involve severe fuselage breaks. Little structural or detailed information is available on several accidents in which a large percentage of the occupants perished. Deep water impact accidents represent less than 10% of the study data base. Water impact usually results in severe damage to the lower fuselage, often accompanied by class 2 breaks in the fuselage and separation of wings, engines, and landing gear. In some cases many occpants drowned after evacuating the aircraft. In other cases the high fatality rate was due to inappropriate action of the cabin crews after the aircraft came to rest.

Last, as might have been anticipated, the overall survivability generally decreases as the major structural damage to the aircraft increases. For categories 5 and 6, known fatalities due to fire and to trauma appear in almost equal numbers. These categories also have the largest percentages of undefined fatalities. The dashed line in figure 10 is an extension of the fire fatalities curve if one adds all of the undefined fatalities to the fire fatalities.

Category 1 accidents in Table 12 experienced only minor structural damage. There were 3 hull losses and 53 fatalities due to fire. Two accidents involved fires, caused by separation of an engine, that resulted in a catastrophic explosion of the wing tanks. In both instances fatalities occurred when tanks exploded while the aircraft were being evacuated. Another accident involved a fire due to penetration of the wing tank by debris thrown up from landing gear. In this instance the aircraft was successfully evacuated but was destroyed by fire.

Category 2 accidents involved only 1 fatality. In this case the trauma fatality occurred as the aircraft penetrated the airport terminal (the purser was killed when the hull was ruptured by a building column). This accident is an anomaly. There were 12 hull losses, 2 of which were due to slowly spreading fire. Two accidents involved engine separation and fuel line fires while another accident was a friction fire due to nose gear collapse.

Category 3 involves 225 fatalities of which 55 are due to non-tank rupture fires, 165 to drowning, and 5 to trauma.

Category 4 accidents involve at least 722 fire related fatalities and 5 trauma fatalities. There are 3 accidents involving 179 occupants and 130 fatalities that are undefined. The specal case DC-8 accident was placed in this category because of the major fuel spill resulting from tank rupture following engine/pylon separation. Drownings account for 18 fatalities, at least 15 of which occurred after evacuation. In most accidents involving drowning, few details are available. In one well-documented case the drownings are thought to have occurred after evacuation and trauma fatal ties were due to seat separation, floor distortion, and to occupants who did not use their seat belts.

Category 5 involves 934 fatalities of which 45% are of undetermined causes. Of the known causes of fatality, 335 are related to fire and 210 are related to trauma.

Category 6 involves 1547 fatalities of which 59% were of undetermined causes. Of the known causes of fatality 189 are related to fire and 190 are related to trauma. In 4 accidents only the fate of the flight deck crew is defined although there are indications of cause with terms as "many" or "most". The enormity of many accidents and shortage of pathological skills preclude accurate postmortem determination of cause.

DEFINITION OF ACCIDENT SCENARIOS

Recognizing that each crash sequence is unique, the definitions of the crash scenarios are broad in nature, rather than specific, and are intended to cover a range of accident occurrences including rather severe conditions that are marginally survivable. The purpose of defining such scenarios are for accident classification to assist in the identification of crash technology phenomena and to allow for the study of structural failure mechanisms under specified impact conditions. After an analysis of the structural damage and injury causing mechanisms three basic crash scenarios evolved: "Air-to-Surface, Hard Landing"; "Air-to-Surface, flight into obstruction"; and "Surface-to-Surface, overrun".

Air-To-Surface, Hard Landing

This scenario considers those types of accidents in which the aircraft impacts a level surface from the air, and is characterized by a high sink rate with wheels up or down, with the airplane in a symmetric nose-up or nose-down attitude typical of a hard landing or approach accident.

Crashes on final approach usually occur because the aircraft is not where the pilot thinks it is. The forward speed of the aircraft is between the speed for flap deployment (160-175 kts) and stall (120-126 kts). The rate of descent is between 10 and 40 ft/sec. The angle of the aircraft relative to the ground (pitch) is dependent on the slope of the ground and the attitude of the aircraft. The airplane attitude is assumed symmetrical with $+15^\circ$ pitch, with impact on the runway or within 600ft of the runway. The aircraft gross weight is weight at takeoff less weight of fuel burned.

For landing accidents, forward speed may be between the prescribed landing speed and stall speed. Some instances of higher speeds were noted, but these cases resulted in overruns. The pitch of the aircraft varies between 3-4 degrees nose down/up to the nose-up stall angle. Rate of descent is between 10 and 40 ft/sec.

To further explore the effect of rate of descent on fatalities a graph of fatalities as a percentage of total onboard for air-to-surface approach accidents, as a function of sink rate, is plotted in figure 11. In figure 11(a) the data from ref. 19 is presented, in 11(b) the data from ref. 20, and in figure 11(c) the data from ref. 21. Recognizing the fact that following initial impact, subsequent hazards may be encountered such as impact into columns, ditches or other obstructions the data plotted in figure 11 should only be viewed as indicating a trend. Furthermore, the accidents in which a large percentage of the fatalities are fire related are shown as solid symbols. Reviewing the solid and open symbol data for all three data bases indicates a general increase in trauma-related fatalities occurring at aircraft sink speeds of approximately 25 fps and above. This trend shows an inherent structural capability of the airframe to provide a good measure of load attenuation in the vertical direction. In figure 12(a), (b), (c) the percent injury to total onboard is plotted as a function of sink rate for the same air-to-surface approach accidents as in figure 11. Again, the accidents involving a high percentage of fire-related fatalities are shown as solid symbols. The data exhibit no apparent trend indicating that injury-causing mechanisms may be more local in nature than global. The accident data does show injuries occurring at a sink speed of 10 fps and above which coincidentally is approximately the landing gear design sink speed.

Air-To-Surface, Flight Into Obstruction

This scenario considers those accidents in which an airplane encounters a hostile environment at impact such as during an undershoot. In this scenario the hazard and terrain conditions have a significant influence on the severity of damage the airplane sustains. The hazards include ravines, embankments, lights, poles, trees, dikes, buildings and vehicles. These accidents can be generally described as controlled or ucontrolled collisions with an obstacle or hostile terrain (undershoot) occurring near the airport (from 400 to 4000ft off the runway) or in some cases several miles from an airport. If the accident occurs during the landing or approach phase the airplane is in a level attitude, with $0^\circ - +15^\circ$ pitch, and approximately zero roll and yaw. If the accident occurs during takeoff the pitch can range from $0^\circ - +45^\circ$, roll from $+5^\circ - +45^\circ$, and the yaw from $0^\circ - +10^\circ$. The ranges of forward speed and sink speed are from 120 - 200 kts and from 10 to 40 ft/sec., respectively. The hazards and terrain conditions have a significant affect on the structural damage and airplane post-impact behavior.

Surface-To-Surface

This scenario considers those accidents in which the aircraft is on the ground and encounters obstructions. The accident is characterized by horizontal motion of the airplane into a hazard such as during take-off abort or landing overrun. The sink speeds, including ground slope effects, range from zero to design sink speed. The forward velocity ranges from 70 kts to rotation speed with the airplane in a level attitude with some swerve. The damage sustained by the airplane is a function of the hazard encountered and ranges from paved surfaces, and hard ground (sliding contact), to ditches, humps, vehicles, light poles, buildings, and soft earth.

Finally, classifications of scenarios are not static but are influenced by airplane and airport design changes. New accident types coming into the data base should have a significantly different distribution from those of the first 20 years. This distribution might be expected to be strongly affected by improvements in accident avoidance techniques and by reduction of hazards on and around airports. Development of fire-suppressing fuel additives could not only alter the distribution of accident statistics in the scenarios, but could change the significance of structural component participation. Consequently, the scenarios should be reviewed at intervals to ensure their continuing applicability. Further, the scenarios should reflect current aircraft behavior as well as data drawn from historical accident reports.

STRUCTURAL FEATURES AND SUBSYSTEMS THAT CONTRIBUTE TO OCCUPANT INJURIES AND FATALITIES

The structural behavior of transport aircraft in accidents involving substantial hull damage, that are impact survivable, will contain the loss, destruction, or damage of one or more structural components or subsystems. During the sequence of events as the destruction occurs and the aircraft comes to a stop, the lives of persons onboard are being jeopardized. In the 176 accidents reviewed in the combined data base (fig. 6) it was determined that the most critical event in the crash sequence that caused most fatalities was the release and ignition of fuel creating a fire hazard. For those persons not injured by impact, the probability of survival was determined by time (measured in minutes and seconds) and by obstructions in the escape route. In order to define approaches to improve the crashworthiness of transport aircraft it is necessary that the involvement of the structural components, systems, and subsystems be determined and the sequence of events and interaction of their involvement in a variety of accidents be well understood. (ref. 19).

Discussion of the major hazards, the dominant structural components, and the interaction as relating to survivability is discussed in the following sections.

Failure Mechanisms and Injury Types

In the review and study of historical accident data various structural failure mechanisms can be identified and are listed in Table 13. In the sequence of events occurring in an accident several of these failure mechanisms may be involved and may interact with one another. The types of injuries that occur are identified in Table 14 (ref. 19).

The structural components are the landing gear, pylon/engine, wing box structure, fuselage, fuel distribution system, floor structure, seats/restraint systems, cabin interior, and entry and escape doors. The landing gear includes nose gear, wing mounted main landing gear, and wide-body fuselage mounted gear. Pylon/engine include wing pod mounted engines and aft body engines. Wing box structure is concerned basically with fuel tankage and primary load carrying members. Fuselage includes lower fuselage, (bottom of fuselage to the cabin floor structure) and upper fuselage (floor structure to crown). Cabin interiors include seats, overhead storage, galleys, closets, dividers, lavatories, ceiling panels, sidewalls, etc.

Subsystem Participation

The crash dynamic response of these various components, their interaction with other components, and the direct result of this action, are given in Table 15 (ref. 19). The frequency of occurrence or participation of each of these structural system failures in the data base of accidents considered in ref. 19 is given in Table 16. The diagonal shows the total participation of any one component while the off-diagonal values show co-participation of other components. The data presented on cabin interior, seats, doors, floors, and body fuel lines are cited in the accident data reports. However, in field investigations of accidents interior structural component failures are not consistently documented and omission of a particular component does not necessarily indicate that no failure has occurred.

Subsystem Participation and Accident Severity

In Table 17, the participation of each structural component and damage category (as defined in Table 11) is presented as a function of accident scenarios (ref. 19) and subsets within these scenarios. On the basis of fatalities in percent of occupants, flight into obstructions is the most lethal accident followed by air to surface, unclassified, and then surface to surface. This order tends to agree with the total energy to be dissipated in the crash. The frequency of fire, while not independent of the total energy, further increases the lethality of the accident. Considering total fatalities, the ranking of the accident scenarios are air-to-surface, flight into obstructions, surface-to-surface and unclassified. No single scenario appears to be "the major type for lethality"; rather each must be studied to fully understand the crash response of aircraft. Likely candidate scenarios would be air-to-surface impact on gear, surface-to-surface - low obstruction and flight into obstruction - impact column.

Structural Factors in Fatalities

The participation of structural factors in fatalities is shown in figure 13 (the number of fatalities coming from Table 12. The major factor in fatalities is fire/smoke, the unknowns representing a combination of trauma and fire. The role of trauma injuries in fire fatalities is undefined. An assessment of the interaction and role of these structural components in a crash environment is presented in Appendix A. A more thorough assessment is presented in references (19), (20), and (21).

POTENTIAL FOR IMPROVING CRASH PERFORMACE

In this section, potential research areas in aircraft structural subsystems are identified. Structural factors in fatalities are reviewed from Appendix A to indicate those systems for which the greatest gain in crashworthiness might be achieved. Research areas are discussed and some approaches are presented. Finally an assessment of the potential for improvement of structural systems is given.

The accident performance of current aircraft is the result of continuing engineering effort, based on accident experience, to improve occupant protection. Certification requires protection of the occupant in minor accidents. Depending on the details of a very severe accident, there appear to be zones of survivable environment within the aircraft even under severe crash conditions.

From the review of accident data for structural system participation, total fatalities have been divided into three groups; trauma, fire/smoke, and drowning. In some cases (Table 11- category 6) trauma injuries have resulted in fire/smoke fatalities through incapacitation of the occupant both inside and outside of the aircraft. As regards fire/smoke and drowning categories, aircraft evacuation problems have also resulted in fatalities.

Fire Hazard

Fire/smoke caused the most known fatalities, followed by trauma, and then drowning, Table 12. The greatest gain in crashworthiness might result from containment of fuel, which would eliminate or reduce the fire hazard. Factors that affect the integrity of the fuel tanks need to be understood. Severe fuel fires have accounted for, directly or indirectly, approximately 36% of the fatalities in the study of 153 impact survivable accidents (table 12). Hazards consist of burns from flame and hot gases, inhalation of smoke/fumes from fuel fire, inhalation of smoke/fumes from burning airplane/ baggage/passenger materials (ignited by fuel fire), and panic/stampede of passengers due to fire/smoke effect.

To prevent or reduce the numbers of these types of fatalities, research areas are identified (listed in order of possible effectiveness):

(1) Fuel Containment

(a) Develop tank vessel/structure to be more resistant to tears, rupture, puncture, etc.

(b) Develop wing box structure (assuming integral tank design) that will fail at predetermined locations when overload forces occur and include double fuel tank ends at these locations. Thus, wing separation/failure at these "fuse" points between the double tank ends may avert massive fuel spills.

(c) Fuel tank explosions cause massive rupture of the vessel and instantaneous enlargement of the severe burn area. To eliminate or reduce the probability of a tank explosion, it is necessary to provide a flame arrestor media that will act as a deterrent to propagation of an explosive flame front. This media could be a metallic resistant material such as aluminum foil or an open-cell plastic foam that has a high melting temperature and is compatible with hydrocarbon fuel.

(d) Develop fuel transfer/feed lines that are more resistant to rupture and, in event of rupture, provide automatic shut off of fuel flow.

(2) Tank Rupture

(a) Main landing gear collapse or separation allows the wing box to scrub on the runway or terrain and to impact low objects or allow engine pods to scrub and separate. Main landing gear design that is more resistant to collapse or separation due to hard landings or travel over rough/soft terrain would be effective in reducing the number of fire related accidents (table 16) in which tear or rupture of the wing lower surface has occurred.

(b) Engine separation and tumbling under the wing has caused rupture or puncture in the wing box. Engine to strut or strut to wing design should be developed to reduce probability of separation.

(c) Fuel spill ignition has resulted from engine separation. During this occurrence the separation and arcing of electrical power leads can ignite fuel from broken feed lines. Designs to minimize arcing should be developed.

(3) Fuel Characteristics

(a) Anti-misting fuel research and development should continue. This technique has the potential to reduce fatalities by reducing the probability of fuel vapor explosions and by delaying the spread and intensity of fire in massive fuel spills.

(b) Jelled or emulsified fuel research should also be considered. From a safety standpoint their viscous nature and low rate of vapor release are desirable characteristics. However, compatibility of emulsified fuels and turbine engine performance must be considered.

Evacuation from the Aircraft

In most accidents, particularly those involving severe fuel fires, the speed with which crew and passengers are evacuated has a major effect on the number of survivors. Experience indicates those occupants that require more than one minute to evacuate may not survive. This is due to fuel smoke and flame burning through the fuselage or entering via a rupture in the fuselage skin. Anything that hinders or delays passenger/crew movement within the passenger compartment must be considered a hazard that requires research and study.

(a) Entry, galley, emergency exit, and cockpit door design should be evaluated for both jamming and blockage. This includes door frame warpage, cabin floor uplift in the vicinity of the door area, door opening mechanism, sliding door tracks, and adequacy of door viewing windows. Passenger panic blockage of door opening areas should be considered during door design.

(b) Overhead passenger storage compartments often open on impact and spill contents or collapse/separate from the fuselage structure so as to injure passenger heads and block/trap passengers in their seats. Contents and debris block aisles and hinder passenger movement to exits. Overwing exits have been blocked by collapsed overhead compartments.

(c) Passenger and crew seat separations or collapse can trap passengers in the seat area and, in some cases, block aisles needed for evacuation. In some cases seat separations have resulted in passenger injury which delayed or prevented evacuation and resulted in death due to fire or smoke.

(d) Partial blockage of aisles and exit areas by galley contents and interior and miscellaneous debris has occurred in about 15% of the accidents studied. However, in only a few of these was the debris more than just a slight hinderance in the evacuation. In general the galley debris concentrates in the area of galley service doors. Since galley displacement is an infrequent occurrence, research should concentrate on containing galley contents.

Structural Break-Up

Structural break-up and excessive impact loads have resulted in trauma fatalities and injuries. These represent approximately 12.5% of all fatalities in the 153 potentially impact survivable accidents (Table 12). Most of the trauma fatalities occur within the fuselage area but a few are a result of passengers being thrown out when fuselage break-up occurs. In many cases trauma injuries are not identifiable because they result in unconsciousness or inability to evacuate the aircraft or the fire area outside the aircraft and therefore death occurs due to fire. Consequently, both the percentage of fire fatalities and trauma fatalities are conservative since 45% of the fatalities occurring are classified as "unknown" simply because it can not be determined if they were solely due to fire or trauma but are a combination of both (see Table 12, figure 10). To prevent or reduce the number of trauma fatalities, detailed studies should consider the following research areas:

(a) Fuselage Breaks - Of the 64 accidents involving breaks in the fuselage, 23 reported that one or more persons were ejected or fell out of fracture holes in the fuselage resulting in death or injury. Similarly, in 13 accidents it was also reported that one or more persons stepped or crawled out of the break (most of these could probably also have evacuated through available doors and hatches). Study and research aimed at improving fuselage structural integrity, particularly breaks and separation, would provide a substantial reduction in trauma fatalities.

(b) Fuselage Floor - Elevation or displacement upwards of the fuselage floor was reported in 36 accidents. Passenger seat elevation, which caused or contributed to serious injuries to passengers sitting in the seats, was reported in 9 accidents. Localized floor displacement has also contributed to passenger and crew injuries during evacuation. In most cases floor beams were displaced upwards in addition to the floor panels. Development of a floor beam and floor panel assembly that is more resistant to both uplift and separation would reduce trauma injuries to seated passengers and probably reduce fatalities by not blocking or restricting evacuation routes.

(c) Seat Load Limiting and Occupant Retention - While it is difficult to establish a numerical measure of seat and occupant retention performance in accidents, research on methods of limiting crash loads on occupants through seat design should be continued. Occupant restraint systems require further study. The floor track/seat/occupant/restraint system response to the various crash loadings should be understood. Effort should be made to establish the injury tolerance limits of the commercial aircraft occupant.

Effects of Water Entry

Accidents in which aircraft impact water or come to rest in deep water involve special hazards. Drownings occurred in 11 of the 16 water related accident cases in the data base. Over two thirds of the drowning fatalities occurred in six of the accidents (air to surface) which involved breaking of the fuselage at impact. The other five accidents involved rupture or tearing of the lower fuselage surface which allowed rapid entry of water.

(a) To reduce or possibly eliminate fatalities due to drowning, study and research should center on improving the fuselage pressure vessel structural integrity, primarily to eliminate fuselage breaks and lower surface tears. Aircraft floatation should be assured if water touchdown occurs at final approach speed and at a touchdown attitude.

(b) In 3 of the 11 water entry accidents the onboard life rafts and vests were used effectively. In the other 8 accidents, onboard rafts were not used, were inflated inside the aircraft, or there were no rafts onboard. Research of this emergency equipment should include consideration of external stowage and deployment of rafts.

Assessment

The potential for improved crash performance for structural subsystems has been assessed to provide some guidance for the planning of research programs. Current structural systems are being designed with current crashworthiness and methods technology. The potential for improved performance is assessed relative to the crash function.

Research into the crash behavior of structural subsystems consists of both analysis and test. Emphasis is placed on treatment of subsystems because the subsystems must perform their crash function in order to achieve crashworthiness for the complete aircraft. Further, it is in detailed mechanisms of failure that engineering changes may be effected. In addition, detailed crash response of an isolated subsystem may be better measured than from complete aircraft testing. On this basis the assessment in Table 18 is presented.

The rating potential for improved performance is given in relative terms; C having good potential, B, being better, and A, being highest. These ratings are subjective and do not reflect the difficulty in advancing the technology. It is expected that some ratings will change as future research and development programs progress.

Analytical research treats the methods of modeling the subsystem to depict detailed crash response. Subsystems of imediate interest are wing tankage, seat/occupant, floor/seat/occupant, and fuselage sections. In this endeavor, the full power of analytical programs may be used to represent the structure in detail. Results of these analyses should be validated with subsystems tests.

Testing of structural subsystems will permit identification of detailed failure mechanisms and sequences of events in simulated crash conditions. In addition, these results may serve as a basis for comparison for the evaluation of advanced material concepts. Advanced material applications for subsystems should also be tested and evaluated. As the applications advance, new subsystem specimens may have to be fabricated, tested, and evaluated.

CONCLUDING REMARKS

Current jet transport design methods are continually updated or modified based on knowledge gained from transport accident data. A study of transport accident data was undertaken in a joint research program sponsored by the FAA and NASA and reported in contract reports (refs. 19, 20, 21). Some of the results of these studies have been highlighted in the present report. There is a point reached in the study of accident data, however, particularly on the condition and details of the airplane cabin interior, in which the omission of data becomes evident and it cannot be assumed that it did not occur, but rather that it did not get reported. Thus, the causative factors related to transport fatalities may not be well defined when many factors interact in the cabin area or when the accident scenario is complex. However, much can still be learned from the historical study of accident data.

It became evident from the accident data study that the greatest potential for improved transport crashworthiness is in the reduction of fire related fatalities. Quoting from ref. 19, research relating to suppression of fire merits the highest priority. Time is a critical element associated with escape when a severe fuel fire exists outside the aircraft or when the aircraft is sinking in deep water. If flame and smoke enter the fuselage passenger area immediately after the aircraft comes to rest, the probability of escape is reduced substantially. Retaining fuselage integrity and delaying entrance of smoke and flame is essential if survivability is to be enhanced. Debris and obstructions that hinder movement of persons on the escape route cause delays that reduce the probability of survival. Consequently, factors that would increase the available time for egress is essential. Fuel additives as in the anti-misting kerosene research program, rupture resistant fuel tanks or fuel cells, and structural improvements to protect fuel tanks and occupants should be subjects of research.

Second, structural integrity of fuel systems, fuselage, and landing gear are leading candidates for improved crashworthiness. Structural integrity of fuel systems is a key factor in suppression of post crash fire. Integrity of the fuselage contributes to the reduction of fire related fatalities by preventing or delaying the entry of fuel, fire, and smoke and by maintaining egress routes. Main landing gear that are more tolerant to off-runway conditions would continue to provide ground clearance for the wing and engine pods thereby reducing the hazard of wing breaks, tearing of tank lower surfaces, and engine pod scrubbing or separation.

Trauma fatalities have predominated generally, when the energy absorbing protective capability of the aircraft structure has been expended and the aircraft has experienced major structural damage. Trauma fatalities might be reduced, however, by improving the airframe energy absorption capability and structural integrity. The dynamic performance of current occupant seat/restraint systems are not well understood and the accident data does not define adequately the relationship between occupant response and structural dynamic characteristics of the seat, floor, and fuselage. Only recently has mathematical modeling of the seat and occupant progressed to where some of this behavior can be more thoroughly explored. Of particular concern is the dynamic response of the occupants in new seats compared to conventional seats as both seat and occupant interact with floor acceleration pulses. This becomes particularly important for applications of advanced materials. The crash performance of structural components made from advanced materials must be compared to that of current structural components. Differences in performance must be assessed for their effect on accident performance of the complete aircraft. Impact response mechanisms of advanced components must be understood in order that accident structural performance might be optimized.

New occupant protection concepts for advanced materials may be required. Current metal aircraft have inherent properties contributing to crashworthiness protection in addition to other design conditions that may not be present in aircraft designed with advanced materials. Of particular concern are wing tanks, fuselage integrity including energy absorption, and the floor/seat/occupant/restraint system interaction. Consequently, it may be necessary to introduce new approaches to occupant protection.

REFERENCES

1. Pinkel, I. I.; Preston, G. M.; and Pesman, G. J.: Mechanism of Start and Development of Aircraft Crash Fires. NACA Research

ORIGINAL PAGE IS
OF POOR QUALITY

Memorandum E52F06, August 1952.

2. Eiband, Martin A.; Simpkinson, Scott H.; and Black, Dugald O.: Accelerations and Passenger Harness Loads Measured in Full-Scale Light-Airplane Crashes. NACA TN 2991, August 1953.

3. Reed, W. H.; Robertson, S. H.; Weinberg, L. W. T.; and Tyndall, L. H.: Crash Tests of a Douglas DC-7. FAA Report ADS-37, April 1965.

4. Bigham, James P.; and Bingham, William W.: Theoretical Determination of Crash Loads for a Lockheed 1649 Aircraft in a Crash Test Program. FAA Report ADS-15, July 1964.

5. Thompson, William C.: Model Ditching Investigation of the Boeing 707 Jet Transport. NACA RM SL55K08, Nov. 21, 1955.

6. Vaughan, V. L., Jr.; and Alfaro-Bou, E.: Impact Dynamics Research Facility for Full-Scale Aircraft Crash Testing. NASA TN D-8179, 1976.

7. Alfaro-Bou, E.; and Vaughan, V. L., Jr.: Light Airplane Crash Tests at Impact Velocities of 13 and 27 m/sec. NASA TP-1042, 1977.

8. Castle, C. B.; and Alfaro-Bou, E.: Light Aircraft Crash Tests at Three Flight Path Angles. NASA TP-1210, 1978.

9. Castle, C. B.; and Alfaro-Bou, E.: Light Airplane Crash Tests at Three Roll Angles. NASA TP-1476, 1978.

10. Vaughan, V. L., Jr.; and Alfaro-Bou, E.: Light Airplane Crash Tests at Three Pitch Angles. NASA TP-1481, 1979.

11. Vaughan, V. L., Jr.; and Hayduk, R. J.: Crash Tests of Four Identical High-Wing Single Engine Airplanes. NASA TP-1699, 1980.

12. Castle, C. B.: Full-Scale Crash Test of a CH-47 Helicopter. NASA TM X-3412, Dec. 1976.

13. Hayduk, R. J.: Comparative Analysis of PA-31-350 Chieftain (N44LV) Accident and NASA Crash Test Data. NASA TM X-80102, 1979.

14. Alfaro-Bou, Emilio; Fasanella, Edwin L.; and Williams, M. Susan: Determination of Crash Test Pulses and Their Application to Aircraft Seat Analysis. Paper 810611 SAE Business Aircraft Meeting, Wichita, KS, April 7-10, 1981.

15. Carden, H. D.; and Hayduk, R. J.: Aircraft Subfloor Response to Crash Loadings. Paper 810614, SAE Business Aircraft Meeting, Wichita, KS, 1981.

16. Hayduk, R. J.; Thomson, R. G.; Wittlin, G.; and Kamat, M. P.: Nonlinear Structural Crash Dynamics Analyses. SAE Paper 790588 SAE Business Aircraft Meeting, Wichita, KS, April 3-6, 1979.

17. TR60-77: Crash Injury and Crashworthiness Final Report. Contract No. TC-624, Flight Safety Foundation, December 1960. TREC Tech. Report 60-77, AvCir 70-0-128.

18. Turnbow, J. W.; Carroll, D. F.; Haley, J. L., Jr.; and Robertson, S. H.: Crash Survival Design Guide. USAAVLABS Technical Report 70-22.

19. Widmayer, E.; and Brende, Otto B.: Commercial Jet Transport Crashworthiness. Contract No. NAS1-16076, Boeing Commercial Airplane Company, March 1982, NASA CR-165849, DOT-FAA-CT-82-86.

20. Cominsky, A.: Transport Aircraft Accident Dynamics. Contract No. NAS1-16111, McDonnell Douglas Corporation, March 1982, NASA CR-165850, DOT-FAA-CT-82-70.

21. Wittlin, Gil; Gamon, Max; and Shycoff, Dan: Transport Aircraft Crash Dynamics. Contract No. NAS1-16083, Lockheed-California Company, March 1982, NASA CR-165851, DOT-FAA-CT-82-69.

22. Anon: Turbine-Engined Fleets of the World's Airlines, 1982. Air World Survey, Supplement to V. 34, no. 2, 1982.

23. Anon: Dimensions of Airline Growth. Boeing Commercial Airplane Company, Y9181, March 1980.

24. Anon: Worldwide Accident Summaries 1964-79. Civil Aviation Authority.

25. Special Study: Passenger Survival in Turbojet Ditchings. NTSB-AAS-72-2, April 1972.

26. Caiafa, C. A.; Nari, L. M.; Chandler, R. F.; and Donell, W. P.: Crash Injury Protection in Survivable Air Transport Accidents — U.S. Civil Aircraft Experience from 1970 to 1978. FAA-CT-80-34, August 1980.

APPENDIX A - INTERACTION OF STRUCTURAL COMPONENTS AND SUBSYSTEMS

The details of the assessment of the interaction of structural components and subsystems are repeated in this appendix as given in ref. 19. Additional information on structural component behavior can be found in refs. 20 and 21. The participation of the components and their contribution to major injury producing hazards, have been categorized in this appendix into the following sections: fire hazard, engine/pylon separation, fuselage break/rupture, blocked egress, landing gear collapse, water entry, and seat collapse.

Fire Hazard and Tank Rupture

Severe fuel fires are the primary cause of most fatalities and result from unwanted release or spillage of tank fuel. In ref. 19 it was reported that 107 accidents involved tank fuel spillage, and 85 of these had fires of varying severity. Spillage directly from the integral tank usually occurs from six types of events: wing box fracture or break, lower wing skin tear or rupture, penetration of the tank by an object, tearing open the wing box during separation of main landing gear or engine pylon, fuel tank ullage explosion, and flow from wing tip vents. In a given accident two or more of these types of spillage sometimes occur. These types and the number of occurrences are shown in figure A1, and discussed below.

(a) Wing box fracture or break - Most fractures occur due to high vertical loads or due to impact with large objects such as trees or buildings. Some wing fractures occur early in the accident sequence and the fuselage continues to slide or move, possibly away from the initial large fuel spill location. Fuel is usually scattered over a large area. In other cases the wing fracture occurs at about the time and point where the aircraft comes to rest and the fuel spill is adjacent, under, or around the fuselage. If fuel ignition occurs, an almost instantaneous severe fuel fire develops; this constitutes the "most hazardous scenario". Damage to other structural components can influence passenger/crew survivability in this situation. Fuselage breaks and fuselage lower surface ruptures can provide immediate access for flame and smoke to the passenger compartment. Damage to the cabin interior such as collapsed overhead storage, galley debris, ruptured floor, and jammed/blocked exits can impede evacuation. The effect of engine/pylon separation (in wing/pylon mounted engines) and gear separation in maintaining ground clearance of the wing does appear to be a significant factor.

(b) Lower wing surface tear - Tear or rupture of the wing lower surface is known to have occurred in eight accidents and probably occured in 19 others. These generally occur when the wing is subjected to scrubbing/sliding on the runway, on rough terrain, or over various objects. Accident records indicate that 13 involved contact with rough terrain, 7 involved sliding over fences and walls, 4 involved sliding on level ground, 1 involved settling on a separated engine, and 1 involved impact with another aircraft. In 26 of these accidents the aircraft was destroyed and 40% had fire-related fatalities.

The hazard evolving from these wing tank tear/ruptures is related to the size of the tank opening, the rate at which fuel is released, the temperature, and whether the fuel was ignited. Many of these occurrences involve severe fires, but they tend to be localized in the wing area and thereby make it possible for persons onboard to evacuate from both ends of the fuselage away from the fire. The interaction and impact that other structural components have on these wing lower surface tears is the same as with wing break occurrences. An increase in the hazard occurs with time (possibly 30 seconds to 5 minutes); fuel ignition on the wing often causes tank explosions that spread the fuel further and intensify the fire. Research should be directed to containing the fuel within the tank or at least restricting the flow of fuel through the rupture or hole in the wing skin.

Landing gear collapse or separation has been a major factor in 50% of the spills and had a lesser effect in about 30% of the spills. Wing mounted engine/pylon separation or collapse during lower surface tear failed to maintain ground clearance in 95% of the cases.

(c) Gear/pylon tear - Tearing away sections or parts of the wing box fuel tank and subsequently releasing large quantities of fuel during separations of main landing gear or of engine pylon is an infrequent occurrence, being reported in seven accidents. However, when it does happen, a severe fuel fire generally occurs. Design philosophy for main landing gear and engine pylon attachment to the wing box should be reviewed to ensure these units are fused for a clean overload separation that does not fracture the integral fuel tank.

(d) Tank explosion - Wing box fuel tank ullage explosions have been reported in 17 accidents and probably occurred in 6 others. In most of these, a severe fire already existed and generally the size or intensity of the fire increased. In most cases it is not known how many, if any, additional fatalities resulted from the tank explosions but it appears from available data that evacuation was usually affected. The initial fire in three accidents occurred at the engine pylon wing interface after engine separation, two of these explosions occurring in flight.

(e) Tank puncture - There are three accidents in which tanks have been punctured by foreign objects. Two of these accidents occurred during aircraft operation and resulted in fires that destroyed the aircraft but for which there were no fatalities. One of these involved puncture by debris from a disintegrating engine and the other involved parts from a disintegrating wheel. The third incident occurred after the accident when the tank was punctured during rescue operations but there was no fire.

(f) Leakage - There are four accidents in which fuel spillage resulted from leaking tanks. Only one accident experienced fire which destroyed the aircraft, but there were no fatalities. While fire hazard is present, these accidents have not been lethal.

Rupture of body fuel lines is a hazard associated with aircraft configurations having aft mounted engines or auxiliary power unit. If fuel tank shut-off valves are activated immediately after a crash, the amount of fuel spilled due to body line rupture is only a minor contributor to the accident severity. However, when the lines are not shut off, the resulting fire has been catastrophic. For example, in the 727 Salt Lake City accident on November 11, 1965, a separated landing gear penetrated the lower fuselage and ruptured a body fuel line. Forty-three occupants died from fire-related causes. As a result of this accident, body lines were strengthened and rerouted to avoid this type of rupture. The only other instance in which body fuel lines are thought to be a major contributor to the severity of an accident is the DC-9 accident at O'Hare on December 20, 1972, where the aft fuselage of a DC-9 struck the vertical tail of an 880 during take-off and probably ruptured a body fuel line. Ten persons perished from fire-related causes in this accident.

The wing tank vent system has been involved in one severe fire accident. In this case, an engine fire spread to fuel dripping from the adjacent wing tank vent at the wing tip, progressed through the vent system and caused a tank ullage explosion. Any studies involving fuel tank design should include the tank vent system and flame suppression.

Engine/Pylon Separation

Separation of an engine from the pylon or separation of the pylon from the wing or body often occurs in accidents involving hard touchdown, undershoot, overrun, or veering off the runway. When one or both main landing gear collapse during these types of occurrences, the probability of engine pod damage or separation is increased. Generally, loss of the engine (forward or reverse thrust) is of minor significance but rupturing of the engine fuel feed line (releasing fuel) and tearing of electrical leads (causing arcing) can be a hazard because of the potential for a fire occurring at the fuel feed line break point. The significance of this pylon-break fire hazard increases if the wing fuel tanks are ruptured and large quantites of fuel are released on the ground. It is believed that the engine and the pylon break fires have been the ignition source for many of the fuel tank fires. Accident reports seldom confirm or deny this, since it is not generally possible to establish from evidence at the accident site what actually provided the ignition source. In some occurrences, friction sparks from wing or fuselage sliding on terrain may have caused ignition of released tank fuel only seconds or microseconds before an engine pylon fire occurred. It is difficult to establish the actual sequence of events. However, from a review of accident data, there appears to be a relationship between wing tank ruptures, severe fuel fires, and pylon break fires that indicates pylon break fires probably provided the source of ignition for released fuel in many accidents.

Of the 153 accidents studied in ref. 19, 94 involved aircraft with engines on wing pods and 59 involved aircraft with engine pods on the aft fuselage. These two groups of air craft were reviewed separately.

(a) Wing pod engine - Of the 94 accidents (including known and probable occurrences) involving wing pod engined aircraft, 67 (71%) involved rupturing of the wing box fuel tank and 68 (72%) involved collapse or separation of the engine pylon to the extent that the engine fuel feed line was torn or ruptured. Fuel fires originating at the fracture of the engine fuel feed line in the pylon are reported to have occurred in 12 accidents and probably occurred in 33 accidents. No fires were reported at this fracture point in 23 accidents. The proximity of the wing pod engine to the wing box fuel tanks has resulted in correlations between engine separation, fuel tank rupture, and a severe fuel fire. Approximately 71% of the accidents involved rupture of the fuel tank and releasing fuel on the ground and, of these, 91% were considered large fuel spills in that the spill area probably was near or adjacent to the engine pylon location. The study shows that 82% of the large fuel spills resulted in severe fires and, in 78% of these, a ruptured engine pylon fuel line fire probably also occurred.

In numerous accidents, separated engine pods have rolled or tumbled under the wing or fuselage as the aircraft slides to a stop. However, accident reports seldom indicate that the pod ruptured the wing box fuel tank. In most cases, investigators are probably unable to determine what objects actually caused tank rupture.

(b) Aft body engine - Of the 59 accidents involving aft body engined aircraft, 38 (64%) involved rupturing of the wing box fuel tanks and 21 (36%) involved collapse or separation of the engine pylon to the extent that the engine fuel feed line was torn or ruptured. Of the 21 occurrences involving engine/pylon collapse or separation, 7 resulted from a very hard touchdown, 7 due to impact with ground objects, and 7 due to high vertical loads as the aircraft slid over rough ground or impacted water. No engine pod separations were known to be caused by pod ground contact during aircraft slide on the lower fuselage.

Fuel fires originating at the fracture of the engine fuel feed line in the pylon are reported to have occurred in two accidents and probably occurred in five accidents. Reports indicate that no fire occurred at this fracture point in 14 accidents. Severe wing tank fuel fires occurred in 26 accidents but, of these, engine/strut fuel line fires were reported in one and probably occurred in 5. This indicates that wing tank fuel, in 77% of these cases, was ignited by something other than by an engine fuel feed line fire. In the other 23% (six cases) the reports do not indicate or show evidence that the engine fuel feed line fire provided the ignition source for the wing tank fuel fire. In most accidents, the investigators are probably unable to determine the actual source of the spilled tank fuel ignition.

Fuselage Break/Rupture

(a) Fuselage break (excluding Fuselage Lower Surface Rupture) - Of the 153 impact survivable accidents used in ref. 19, 64 are known to have experienced one or more breaks in the fuselage and 7 others probably also had breaks. Forty-six of the 64 were fatal accidents. Available data indicates that 39.5% of the persons onboard in the 64 accidents were fatalities. The other 82 accidents did not experience fuselage breaks and 27 of these were fatal accidents of which 20.6% of the persons onboard were fatalities. Of the 64 accidents experienced fuselage breaks, 6 involved the aircraft touching down in deep water and 58 involved the aircraft touching down (impacting) on ground or in swampy areas with shallow water. The six deep water entry accidents in which the fuselage broke into several pieces had a 36.8% fatality rate

(36.8% of those on board) and are discussed under the heading "Water Entry". The fifty-eight ground or swampy slide accidents experienced fuselage breaks due to main landing gear separation/collapse, excessively hard touchdown or hard flat/impact after takeoff, touchdown in areas of trees/buildings/objects or on rocky/rough terrain, or combinations of these conditions. Of these fifty-eight accidents, 39 involved fatalities which had a 52% fatality rate. In 5 accidents (8.6%) landing gear collapse or separation is believed to have contributed to the fuselage breaking; that is, if the gear had not failed the fuselage may not have broken.

The accidents are divided into three groups which are discussed as follows:

1. Twelve accidents involved a slight break(s) or fracture in which fuselage sections did not separate far enough for a person to be ejected or for a person to crawl or step out during evacuation (class 1 of Table 11). These accidents generally occur on or near the airport and are the result of landing overruns, takeoff abort, or veering off the runway. Impact which caused the fuselage break usually occurred after considerable braking decelerations both off and on the runway. Only two of the accidents (16.6%) involved a severe fuel fire, and only 6.3% of the persons onboard in these 12 accidents were fatalities.

2. Twenty accidents involved a clean, wide break in which the fuselage section remained basically intact but separated far enough for a person to be ejected or to crawl/step out (class 2 of Table 11). About 75% of these accidents involved severe fuel fires and 29.4% of the persons onboard in these 20 accidents were fatalities. Approximately half of these accidents involved aircraft impact speeds of 100 knots or more.

3. Sixteen accidents involved considerable destruction of the fuselage sections and in most cases the sections slid or traveled many feet after separation (class 3 of Table 11). During this movement persons were often thrown/ejected from the remains of the fuselage section. In some cases ejected persons were killed from trauma, and in other cases the ejected persons survived because they were thrown out of a fire or burn area. About 93.8% of these accidents involved severe fuel fires and 77.8% of those onboard in these 16 accidents were fatalities In most cases the aircraft speed at impact was well over 100 knots--two of these had an impact speed of 188 and 271 knots, yet some persons survived. Many accidents in this group can be considered to be only marginally survivable.

It can be concluded that the probability of fatalities in accidents resulting in fuselage breaks during ground slides is closely related to aircraft speed at the time of impact. The group of accidents resulting in only slight breaks (class 1) had an average aircraft impact speed of 57 knots and 6.3% of those on board were fatalities. The group resulting in a clean (but open) break (class 2) had an average speed of 83 knots and 29.4% were fatalities. The group resulting in a torn fuselage (class 3) had an average speed of 136 knots and 77.8% were fatalities. (See figure A2). The greater the speed, the greater the fuselage damage and the greater probability of fuel tank rupture causing severe fire. However, even in the worst cases, some persons onboard survived. Design changes that would result in a stronger fuselage that is more resistant to fragmentation should provide a substantial increase in survivability for those onboard.

(b) Fuselage Lower Surface Rupture (excluding fuselage break accidents) - Of the 153 impact survivable accidents in ref. 19, 57 aircraft are known to have experienced considerable damage to the lower fuselage and little or no damage to the upper fuselage (above the floor line). Seventeen of these 57 were fatal accidents, with 17.5% of the persons onboard being fatalities. In addition to the accidents noted above, there are seven accidents that probably experienced fuselage lower surface damage; three of these were fatal accidents with 45.8% of the persons onboard being fatalities.

Lower fuselage tear or rupture generally occurs when the landing gear fails to support the aircraft. Thus, scrubbing on rough surfaces (sometimes even on the runway) rips open the thin skins and body frames. At the same time, wing box fuel tanks are also subject to rupture and fuel spillage. In 37 of 53 ground slide accidents (4 of the 57 accidents were water entry accidents), the wing box was probably ruptured in 32 of these accidents; 25 severe fires resulted and 12 minor or moderate fires.

Lower surface damage accidents are divided into three groups for study purposes: extensive rupture, minor or moderate damage, and those involving water entry (the four accidents involving water entry are discussed under "Water Entry").

1. Twenty-eight accidents experienced extensive damage and rupture of the fuselage lower surface. Eleven of these were fatal accidents with 27.7% of the total onboard being fatalities. A severe fire occurred in 15 of the accidents and 9 of these were fatal accidents. Six other accidents involved a minor or moderate fire with no fatalities.

2. Twenty-five accidents experienced moderate or minor damage of the fuselage lower surface. Of these only three were fatal accidents, with 1.5% of those onboard being fatalities. Six of these accidents involved a severe fuel fire, four involved a moderate or minor fire, and six had no fire reported. Of the three fatal accidents, two had severe fires and one a moderate fire. Six accidents involved the nose gear collapsing aft into the lower fuselage. One resulted in a severe fire (friction

ignited) which destroyed the aircraft and one resulted in a moderate fire (also friction ignited) which resulted in substantial damage. In another case of friction fire, the aft fuselage broke and was dragged on the runway.

In design, the prevention of friction fires is treated by separation of flammable materials from the proximity of friction sparks or heated structure. In operation, rapid action by the airport fire fighting team has reduced the effect of the friction fire.

It can be concluded that the probability of fatalities in accidents resulting in lower fuselage tear or rupture during ground slide is closely related to the occurrence of severe fuel fire. Flame and smoke from fuel burning on the ground below and around the fuselage have, in many cases, rapidly entered the passenger area via openings in the lower fuselage. If openings had not been present, the precious minute or two required for skin burnthrough would probably be adequate for evacuating most or all persons via escape routes away from burn areas. Of the 12 fatal accidents during ground slide, 11 had severe fire and one had a moderate fire.

Blocked Egress

(a) Cabin Door or Exit Jamming or Blockage - Of the 153 impact-survivable accidents studied in ref. 19, reports for only 47 accidents cited occurrences of entry door, galley door, cockpit door, or emergency exits jamming or being blocked by cabin equipment, debris, or outside objects. It is believed that door or exit related evacuation problems also occurred in many other accidents.

Fuselage breaks often provide a handy and expeditious means for some of the passengers and crew to evacuate the aircraft. In 10 of the 47 accidents, where door/exit problems were cited, the reports also indicated that some passengers and crew departed via breaks and holes in the fuselage. In most cases these people could have also departed through available doors or exits. However, in a few cases the fuselage break was probably the only means of escape. In many accidents which involved severe fuel fires, some doors or exits could have been readily opened but were not used because of fire in that particular area outside the fuselage.

Available factual data relating to the 47 accidents citing door/exit problems are tabulated in figure A3. These data indicate that most occurrences (57%) involve doors at the front of the fuselage and only 16% at mid-body and 27% at the aft fuselage. This ratio is expected since in ground slide accidents the forward fuselage is generally the first to impact objects such as buildings, trees, poles, etc. These data also indicate that forward fuselage doors involved jamming in 64% of the cases and blockage in 36% of the cases. Doors in the aft fuselage had approximately the same ratio. Mid-body exits, however, had this ratio reversed with blockage being 64% of the cases and jamming only 36% of the cases. It is probable that the wing box structure provides protection from jamming of the mid-body overwing exits.

Considering all doors/exits, jamming is reported in 59% of the cases and blockage in 41% of the cases. Jamming is generally caused by door frame distortions; however, accident reports seldom provide much detail on what caused the problem. Floor-lift due to upward forces from the cargo area often cause total or partial jamming of doors. The same upward forces may also cause door frame distortion. In a few cases evacuation slides are involved in door jamming. Blockage is generally caused by collapsing of overhead storage compartments and release of the contents. This debris usually results in complete inability to open the door or exit. Spillage of galley contents occurs frequently, which tends to cause a delay in opening the door. In a few cases displacement of a galley or coat storage compartment has caused door blockage, particuarly at the forward fuselage locations.

The number of fatalities that were a direct result of door jamming or blockage can seldom be determined or even estimated from available data. Of the 47 accidents in which door/exit problems were cited, only 24 involved fatalities (2187 total onboard of which 753 or 34.4% were fatalities). Of the 24 accidents with fatalities, 9 had two or more doors or exits jammed or blocked and 41.9% of those onboard were fatalities. In the other 15 accidents only one door or exit jammed or was blocked and 27.1% of those onboard were fatalities.

From this study of door and exit problems during emergency evacuations, it can be concluded that survivability might be increased if floors and structure in the area of each entry and galley door were designed to eliminate jamming of doors, and if overhead storage compartments were designed to resist collapse and reduce door blockage.

(b) Fuselage floor displacement - Displacement and rupture of the passenger floor has resulted in passenger and crew injuries, and has restricted movement of survivors to exits. In some cases the upward movement of the floor has resulted in the jamming of doors or door frames and in other cases doors could not be opened due to debris blocking the door. Generally, floor surface displacement is a result of the structural floor beams being torn, ruptured, and displaced upwards by the impact forces of cargo, cargo containers, separated landing gear or ground objects. The exception to this is floor displacement by the hydraulic action of water when the aircraft touches down in water or rolls into water at high speed--in these cases the floor beam may not be displaced upward.

Of the 153 accidents studied in ref. 19, 36 are known or reported to have experienced passenger or crew area floor displacement or rupture, and this occurred probably in 4 other accidents. Statistical data on these occurrences are tabulated in figure A4. For study purposes, these 36 accidents are divided into three groups: 15 that did not involve a fuselage break, 17 that did involve a fuselage break, and 4 that involved the aircraft touching down or overrunning into water. These groups are discussed as follows:

1. Of the 15 accidents which did not have fuselage breaks, 8 involved displacement upwards of the cabin floor as a result of the nose gear

folding/collapsing aft into the lower forward fuselage cargo compartment or electronic compartment. Displaced cargo or electronic equipment forced the floor up and probably tore or bent the floor beams. In four of these accidents the cockpit door was jammed, and in two the entrance door was jammed or blocked. None of these were fatal accidents; however, one resulted in a friction-ignited fire at the nose gear tires which spread and destroyed the aircraft.

Seven other accidents involved a ground slide in which the fuselage lower surface was torn or crushed upward such that floor and floor beams were displaced upwards in localized areas. In one of these a main landing gear assembly rolled/tumbled under the fuselage and caused much of the damage. In three accidents, an entrance door was jammed or blocked by the floor.

Passenger seat elevations occurred in seven accidents which contributed to passenger injuries. In three accidents passenger seat separations occurred. Accident reports in these cases did not site seat separation or floor displacement as interferring with passenger egress.

2. Seventeen accidents which had fuselage breaks also had areas where the floor was displaced upwards. These accidents tend to be more severe than those without fuselage breaks. If fuselage separation is complete and wide enough for human and seat ejection, the effects of passenger floor elevation or rupture on survivability is reduced. In 13 accidents passenger seat separation was reported and in 9 accidents seat elevation was reported, but in only 4 accidents was passenger egress reported to have been impeded. It is not known how much influence the elevated or broken floor had on passenger egress. Passenger entry door jam was reported in five accidents and crew door jam in two accidents. Cause of these door jams in most cases could not be established with any certainty but was probably due to either floor elevation/rupture or due to fuselage break if the break was adjacent to the door.

3. Crew/passenger floor elevation and rupture occurred in four accidents which involved the aircraft touching down in deep water or rolling into water at high speed. In these cases the lower fuselage surface was torn open and the lower (cargo) area filled with water. Hydraulic action/pressure forced the floor panel upward, causing seat separation in two accidents and seat elevation in

three accidents. Exit doors were found to be blocked in two accidents.

In one accident, the forward closet dislodged. It shifted forward in such a way that the forward entrance door was partially blocked and delayed opening of the door. Also a section of floor came up and created an opening through which two of the crew fell into the lower forward compartment. In another accident, the nose gear separated and tumbled aft, rupturing the lower fuselage. Floor beams and floor panels were elevated causing passenger seats to tilt backwards and block emergency exits on both sides of the fuse lage.

Available accident data provides evidence that displacement, elevation, or dislodging of the passenger/cockpit floor system in localized areas has resulted in passenger and crew injuries and has, in varying degrees, interferred with or delayed the evacuation of pasenger and crew. However, accident reports generally provide very little detailed information on this type of damage unless it is related to the cause of the accident. It is concluded from reviews of available data that a floor system more resistant to tear/rupture/separation, though still flexible, may reduce some of the factors which are believed to impede evacuation of the aircraft.

(c) Cabin interiors - In the accident study, the 45 accidents where cabin interiors have been cited should serve as an indication of possible crash behavior of cabin interior equipment. The 23 accidents where probable participation has been assessed may not include all incidents. In some accidents where at least one feature of the cabin interior participated, participation of other features are probable.

Overhead storage compartments have been assessed with regard to separation, spillage of contents, evacuation blockage, and injury to occupants. Ceiling panels, sidewall liners, and class partitions have been assessed for separation. This separation usually has some effect on egress. Galleys have been assessed for spillage of contents as well as egress blockage. These units are of particular concern since they affect availability of the service doors as an egress route. These assessments are shown in figure A5. Cabin interiors have been a major factor in evacuation in 12 known accidents and a probable factor in 14 accidents. Overhead storage has caused injuries in five known accidents and probably caused injury in three additional accidents.

Figure A6 shows interaction between other structural systems and the cabin interior system. Crush of the lower fuselage is deemed to have occurred in 52 of the 68 accidents. Fuselage breaks are deemed to have occurred in 32 of the 68 accidents. Landing gear separation or collapse occurred in 48 accidents and the gear was retracted in 6 other cases. Floor distortion is deemed to have occurred in 26 accidents. All of these interactions participate in severely loading the structural supports for the cabin interior equipment. Fire was present in 41 of the accidents.

Landing Gear Separation/Collapse

There are 96 accidents in which one or more of the landing gear separated or collapsed. In addition there are 15 accidents in which the gear was stowed or retracted. The effect of gear separation or collapse will be considered, followed by the effect of gear in stowed positions. Some comparison of the two effects will be made.

Referring to table 16, the total occurrences show that for 95 cases of gear involvement (1 accident involves debris from the gear damaging the aircraft) there were 80 hull losses, 64 fires, 71 tank ruptures, 46 wing mounted engines/pods separated (11 cases of engine separation involve aft mounted engines), 62 fuselage breaks or crush, 38 door hatch involvements, 33 floor distortions, 33 cases of debris, and 26 seat involvements.

Direct effects of gear separation are: separation of wing pod mounted engines; rupture of fuel tanks by failing to maintain ground clearance and by the separating gear tearing a wing box; and damage to the lower fuselage by crushing, friction, and by breaks. Secondary effects are fire due to fuel spillage from ruptured fuel lines and tanks and to friction, floor distortions, door/hatch problems, seat separation, and debris due to the distortion and breaks of the fuselage as a result of ground contact. In 67% of the accidents all gear separated or collapsed, while in 22% only the main gear separated or collapsed, and in 9% only the nose gear separated or collapsed and in 2% the nose gear and one main gear separated or collapsed.

Gear separation or collapse was involved in tank rupture in 17 cases of lower surface tear, 12 cases of wing breaks, 14 cases of wing box tear, and 4 cases of tank leakage. This fuel spillage resulted in 42 fires. Thus gear separation or collapse is a factor in 64% of the fires that occurred when the landing gear participated in the accident. Using small, medium, and large as the degree of involvement, the gear was a large factor in 26 of the 42 fires, a medimum factor in 4 of the fires, and a small factor in 12. With respect to fatalities, there were 28 accidents with fire related fatalities and 24 accidents with trauma deaths.

Lower fuselage crush occurred in 53 accidents with gear separation being a large factor in 37 cases. Lower fuselage crush has a secondary effect on door/hatch jamming, on separation of seats, and on cabin interior debris. Gear separation was a large factor in 9 cases of fuselage breaks. For 15 accidents in which the gear was known to be retracting or in the stowed position, there are ony 5 cases where having gear extended may have prevented the crash. These cases mostly involve extensive slide-out, but occurred during aborted takeoffs or flight activities for which the gear is normally retracted.

From the above discussion it may be concluded that development of gear more tolerant to conditions that cause separation would result in some increase in crashworthiness. Further, when separation does occur, the wing box should not tear open.

Water Entry

Accidents in which aircraft impact on water involve special hazards. In air to surface accidents involving impact in water, 46.3% of the occupants drowned. In 11 of the 16 water accidents water was an important factor in survivablity. These 11 cases are reviewed.

Water entry accidents of concern appear to have some common factors. First, they usually occur at night. Second, there is usually a relatively rapid loss of flotation resulting in a portion or all of the aircraft sinking. Third, while there has been confusion, most occupants have been able to evacuate the aircraft. Finally, many of the drowning fatalities occur after the occupants have left the aircraft.

Assessment of the water entry accidents is shown in figure A7. The accidents are divided into two groups: high-energy impact and slide/roll into the water. There are eight high-energy accidents, and three cases where the aircraft rolled or slid into the water. For all of these accidents the fuselage experienced either lower surface crush or had one or more breaks. In all the higher energy impacts there was a loss of floation attributed primarily to fuselage damage. While tank rupture resulted in some loss of buoyancy, the major effect of tank rupture was to expose occupants to fuel (chemical) burns and to make everything slippery.

Six water entry accidents in which the fuselage broke into several pieces (fuselage break,A7) had fatalities (36.8% of those persons onboard). In five of these accidents one section of the fuselage sank rapidly: some of the passengers and crew probably were ejected or fell into the sea without benefit of survival gear and others were trapped inside. The other fuselage sections floated briefly, allowing evacuation into rafts or floating slides. In other accidents the fuselage sections floated briefly, but 84% of those onboard drowned. Survivor reports indicated that in at least two accidents, interior and carry-on debris blocked evacuation routes and in two other accidents some exit doors were jammed. In another, the passenger compartment floor was displaced upward restricting evacuation.

Touchdown in deep water or rolling into deep water at high speed caused the lower surface of the fuselage to be torn or ruptured but the fuselage did not break (lower fuselage crush,A7). Three of these four lower fuselage crush accidents resulted in extensive lower surface damage and the aircraft sank rapidly. All three were fatal accidents with 18.1% of persons onboard being fatalities. One accident resulted in moderate damage to the lower surface as the aircraft rolled into water and came to rest on its gear with the water level at or slightly above the cabin floor. There were no fatalities. However, in these accidents the aircraft floated at least 5 minutes and in most cases 10 to 20 minutes, thus allowing adequate time to escape. In three of the four accidents it was established that the onboard rafts and floating slides were not used.

The floor system was known to be disrupted in six of the eight high energy water entry accidents. Disruption was due in part to the hydrodynamic forces of water entering the fuselage underside through breaks in the fuselage. A part of this disruption resulted in displacement and elevation of floor beams with subsequent separation of seats, which contributed to problems in the evacuation of the aircraft. In addition, doors were jammed and debris from cabin interior systems was present.

Accidents where aircraft skidded or rolled into water experienced similar damage as the high energy impact, but to a lesser degree, However, close proximity of land substantially reduced drowning. The 15 drownings in the DC-8 Rio de Janeiro accident (table 8) were attributed to disorientation of the occupants after they evacuated the aircraft and to improper use of flotation devices. After the DC-9 St. Croix accident (table 8), a special study (ref. 25) was made by the NTSB on water ditching. Here, even though it was known that ditching was inevitable, 23 occupants drowned. There were problems with life rafts, life vests, and seat belts. Other problems with this equipment were encountered in the DC-8 Los Angeles accident (table 8). It is felt that the incidence of drowning could be substantially reduced by better location of life rafts. For instance, placement of rafts above the exits with external access might provide better accessibility.

It can therefore be concluded that in deep water entry accidents in which the fuselage does not break, the survivor rate should be very high with proper crew response/actions using available equipment. Improved crashworthiness might also be obtained by increasing the resistance of the fuselage to breaks and by increasing the resistance of the lower fuselage to water penetration.

Seat Collapse

Seats interface with the occupant and with the structure to which they are attached. Three basic types of seats are of concern: crew seats, flight attendant jumpseats, and the double and triple bench seats, for passengers. Crew seats are single seats that are mechanically adjustable to conform to pilot preference and are attached to the cockpit floor structure. A combination shoulder and lap belt restrain the occupant. Flight attendants' jumpseats may be single or double units attached to a bulkhead and mechanically folded or retracted when not in use. These seats support vertical loads, with the restraint harness transmitting side and longitudinal loads to the structure. Passenger seats are attached to floor tracks and in some designs to the fuselage sides. Floor tracks are attached to the floor structure or to pallets attached to the floor structure. The passenger is restrained by means of a lap belt.

(a) Seat/Structure Interface - For the interaction of seats with structure, no distinction is made for type of seats, but two interactions are of concern with the structure--the effect of a fuselage break and the distortion of the floor. In a fuselage break, seats may be ejected through the break, or may simply separate from a broken floor track. In floor distortion, seats may separate from the track, or may be elevated.

The potentially most lethal of these interactions is ejection through the fuselage break. Survival of the occupant is a matter of chance, depending on many factors such as velocity of ejection, nature of impact area, and the orientation of the occupant at impact. Further, the ejected occupant may be in an area that is exposed to fire or is overrun by the advancing aircraft. Seats located in the vicinity of a fuselage break may be subject to high acceleration pulses due to the redistribution of the stored strain energy as the structure breaks. This frequently results in the separation of the seats due to rupture of seat tracks, seat track attachments or seat structure. Separated seats may then shift position and cause injury or hinder the egress of the occupant.

Seat dislocation caused by floor distortion may be due to separation or to elevation of the seat. Separation may force the occupant into contact with interior objects and may hinder egress. Floor elevation may block egress routes such as over-wing escape hatches, may hinder the occupant in exiting from the seat, or may force contact with the cabin interior. For crashworthiness, it is desirable to keep seats attached in place, and to maintain a survivable volume for the occupant.

There are 48 accidents with identified interactions and another 21 accidents to which probable interactions were assigned. Assessment of these accidents is shown in figure A8. Fuselage break has resulted in 15 certain and two probable accidents where one or more occupant was ejected through the break. Separation of some seats at the break with the seats remaining in the aircraft occurred in 30 accidents with probable occurrence in at least 13 other cases. Seat separation due to floor or fuselage side distortion occurred in 19 accidents with probable occurrence in 5 other cases. Elevation of the seat without separation occurred in 14 accidents with 4 other probable occurrences. Seat detachment (separation) is generally associated with loss of structural integrity due to destruction of the fuselage shell, fuselage breaks, and to extreme distortion of the structure. Detachment may occur if all the seat legs or attachment fittings rupture or if the seat tracks rupture. This indicates that a more compliant seat/floor substructure to accommodate distortion might be more beneficial than an increase in seat strength criteria.

(b) Seat/Restraint System - The discussion of seat/restraint system performance in survivable crashes is presented in two parts. The first part includes those accidents in which some injuries might be related to seat strength performance and in which seat/restraint performance were cited by the accident investigation team. The second part includes serious accidents in which the seat/restraint performance was not cited and in which no injuries that might be related to seat strength occurred.

Thirty-one accidents were found in which seat performance was mentioned in NTSB reports. A detailed review of these accidents indicated that the seats provided some protection to the occupant depending upon the crash loads. The current study drew upon NTSB accident reports and special studies, NTSB Human Factors Factual Reports, NTSB Public Hearing Dockets, and the manufacturers accident files for each accident. A separate FAA study (ref. 26) also treats NTSB data, and includes FAA Civil Air Medical Institute (CAMI) data but does not include the manufacturers files.

For engineering purposes it is necessary to relate seat performance to injury. To do this it was necessary to review the Human Factors Factual Reports and, in some instances, survivor testimony. The NTSB statistical category, "Serious Injury", used in NTSB Accident Reports does not necessarily identify actual physical injury nor relate injury mechanisms to injury. Accident victims who are hospitalized for 48 hours for medical observation, legal considerations, or other reasons are listed as serious injuries even if there is no treatment. An immediate improvement in crashworthiness statistics could be obtained simply by using a more accurate definition of serious injury.

In the accident review in ref. 26, investigators did not identify a single trauma fatality caused by lack of seat strength or seat attachment structure strength. It is recognized that such identification is difficult because of incomplete knowledge of local crash dynamics, fatal injury mechanisms, and survivor testimony. Also, postcrash fire frequently consumes necessary evidence. There are limited, though subjective, indications where an increase in attachment strength may have provided some benefit. For instance, one passenger in the 727 St. Thomas accident (table 8) was ejected in his seat through a fuselage break and died of trauma injuries. This seat was located in the aircraft in the region of fuselage rupture.

It can be observed that injuries are sustained in deforming of seats. The cases discussed in ref. 19 involved serious injury caused by seat/restraint system crash behavior. Of the twenty-nine accidents involving seat citations, twenty-six also involved a hull loss, 19 involved fire, 22 involved at least one fuselage break, 14 involved severe floor distortion, and 4 involved water impact. Seat-related to the head, spine, chest, and pelvis are of concern, although injuries of these types may arise from a variety of other causes. In ref. 19, these injuries are reported the flight deck crew and passengers, while spine and pelvis injuries are reported for flight attendants. There are eight accidents in which flight attendants suffered spinal injuries while seated. In the DC-8 Anchorage accident, one injury occurred when the seat retracted from under the attendant during upward acceleration causing the attendant to fall to the floor. The remaining injuries occurred with the flight attendants in the seat. Two flight attendants had spinal and pelvic injuries in the high longitudinal deceleration 727 JFK accident on June 24, 1975, even though there was no damage to the seat/restraint system. Most of these citations involve instances of seat collapse or partial collapse due to rupture of a hinge, seat attachment fitting, or of the supporting mechanism. The injuries sustained did not cause loss of mobility in most cases.

Four accidents are of concern in accident performance of the flight deck seats. In the DC-8 Portland accident, the right side of the cockpit experienced loss of survivable volume due to impacting a large diameter tree (of the cockpit occupants, only the Captain survived). The First and Second Officer's seats separated while the Captain's seat was attached but was loose and had some seat pan deformation.

For commercial jet transport aircraft, there is little evidence of seat separation with subsequent "stacking" in the forward section of the aircraft. Two exceptions to this are the DC-9 St. Croix accident (table 8) where three double seats stacked due to the impact of some passengers who did not use their lap belts; and the 737 Midway accident (table 8) where two triple seats (rows 14 and 15 A, B, and C) stacked due to severe structural damage to the fuselage in that area. The more severe injuries occur in the vicinity of fuselage breaks and areas of extreme fuselage distortion. This might be expected since these are locations of very high loadings and areas where the airplane structure has lost its ability to protect the occupants

For a more definitive discussion of individual accident cases relative to seat/restraint system performance see refs. 19, 20, and 21. An overall assessment of seat/restraint system performance, as stated in ref. 21, is:

> "The performance of seats with regard to protecting occupants during an accident is generally good provided the structural integrity of the fuselage shell and supporting floor structure is maintained. The most vulnerable area for seat failure appears to be at the attachment to the floor. While seats exhibit desirable deformation characteristics in the process of failing there is little quantitative data available with regard to load vs. stroke characteristics. Presently, static tests are performed to determine strength. The current static requirements appear to account for dynamic effects, possibly because:
>
> 1) seats may have higher strength than is required and,
>
> 2) metal support structure has inherent crush capability which provides energy absoprtion in an overload condition".

TABLE 1. - SUMMARY OF ACCIDENT INJURY LEVELS AS A FUNCTION OF AIRPLANE WEIGHT CLASS (BASED ON REDUCED NUMBER OF STRUCTURAL-RELATED ACCIDENTS)

1964-77 NTSB Data

Airplane Weight Class	SEVERITY OF INJURY				Percentage of Total
	Fatal	Serious	Minor/ None	Total	
B	22	11	111	144	42.2
C	24	17	78	119	34.8
D	16	9	36	61	18.0
E	1	5	11	17	5.0
Total	63	42	236	341	100
Percentage of total	18.5	12.3	69.2	100	

TABLE 2. - SUMMARY OF ACCIDENT INJURY LEVELS AS A FUNCTION OF AIRPLANE WEIGHT CLASS (BASED ON REDUCED NUMBER OF STRUCTURAL-RELATED ACCIDENTS)

1964-77 NTSB Data	SEVERITY OF INJURY				
	FATAL	SERIOUS	MINOR/NONE	TOTALS	% TOTAL
AIRCRAFT DAMAGE					
Destroyed	63	16	10	89	26
Substantial	0	25	220	245	72
Minor/None	0	1	6	7	2
POST CRASH FIRE OCCURRENCE					
Yes	61	19	4	84	25
No	2	23	212	237	70
Unknown	0	0	0	0	
I. SEVERE IMPACT					
A. Controlled Collision	23	4	1	28	
B. Uncontrolled Collision	8	2	1	11	
C. Undershoot	4	2	18	24	
D. Stall	2	1	4	7	21
II. MODERATE-HIGH SINK SPEED					
A. Hard Landing	2	1	24	27	
B. Gear Collapse	1	3	38	42	
C. Wheels Up	0	0	16	16	
D. Retracted Gear	0	0	14	14	
E. Swerve	1	2	26	29	
F. Overshoot	4	6	16	26	45
III. SYSTEM MALFUNCTION					
A. Engine Malfunction	2	9	27	38	
B. Prop. Rotor Malfunction	4	0	3	7	
C. Airframe Failure	1	3	12	16	
D. Fire/Explosion	1	3	15	19	23
IV. COLLISION WITH					
A. Trees	6	0	4	10	
B. Ditches, Fence, Seawall	2	3	0	5	
C. App. Lights, Wires	0	3	7	10	
D. Obstacles (bldg., auto, etc.)	2	0	10	12	11
TOTALS	63	42	236	341	100

ORIGINAL PAGE IS
OF POOR QUALITY

ORIGINAL PAGE IS OF POOR QUALITY

TABLE 3. - SUMMARY OF ACCIDENT TYPES BY OPERATIONAL MODE (BASED ON REDUCED NUMBER OF STRUCTURAL-RELATED ACCIDENTS)

1964-77 NTSB Data

	TAKEOFF * X-Y-Z	LANDING * X-Y-Z	TAXI * X-Y-Z	FLIGHT * X-Y-Z	TOTALS * (T)	X-Y-Z
I. SEVERE IMPACT					(70)	37-9-24
A. Controlled Collision	2-0-0	15-4-1		6-0-0	(28)	23-4-1
B. Uncontrolled Collision	2-1-1	2-1-0		4-0-0	(11)	8-2-1
C. Undershoot		4-2-18			(14)	4-2-18
D. Stall	0-1-4	2-0-0			(7)	2-1-4
II. MODERATE-HIGH SINK SPEED					(154)	8-12-134
A. Hard Landing		2-1-24			(27)	2-1-24
B. Gear Collapse	1-1-4	0-2-23	0-0-11		(42)	1-3-38
C. Wheels Up	0-0-1	0-0-15			(16)	0-0-16
D. Retracted Gear	0-0-3	0-0-10	0-0-1		(14)	0-0-14
E. Swerve	1-1-6	0-0-18	0-1-2		(29)	1-2-26
F. Overshoot		4-6-16			(26)	4-6-16
III. SYSTEM MALFUNCTION					(80)	8-15-57
A. Engine Malfunction	1-6-9	0-2-2		1-1-16	(38)	2-9-27
B. Prop/Rotor Malfunction	2-0-2	1-0-1		1-0-0	(7)	4-0-3
C. Airframe Failure	0-3-1	0-0-3	0-0-3	1-0-5	(16)	1-3-12
D. Fire/Explosion	0-1-1	0-1-4	0-1-3	1-0-7	(19)	1-3-15
IV. COLLISION WITH					(37)	10-6-21
A. Trees		5-0-3		1-0-1	(10)	6-0-4
B. Ditches Fence Seawall	1-3-0	1-0-0			(5)	2-3-0
C. App. Lights Wires	0-1-2	0-2-4		0-0-1	(10)	0-3-7
D. Obstacles (Bldg., Auto)	1-0-1	1-0-2	0-0-6	0-0-1	(12)	2-0-10
TOTALS	11-18-35	37-21-144	0-2-26	15-1-31		63-42-236
	64 (19%)	202 (59%)	28 (8%)	47 (14%)	341	

*X-Y-Z X = NO. OF ACCIDENTS INVOLVING FATALITIES
Y = NO. OF ACCIDENTS IN WHICH HIGHEST INJURY INDEX IS SEVERE INJURY
Z = NO. OF ACCIDENTS IN WHICH ONLY MINOR/NO INJURIES WERE SUSTAINED

(T) = TOTAL NO. OF ACCIDENTS

TABLE 4. - SUMMARY OF ACCIDENT TYPES BY AIRPLANE WEIGHT CLASS, BASED ON REDUCED NUMBER OF STRUCTURAL-RELATED ACCIDENTS

1964-77 NTSB Data

PRIMARY ACCIDENT TYPES	WEIGHT CLASS B *X-Y-Z	WEIGHT CLASS C *X-Y-Z	WEIGHT CLASS D *X-Y-Z	WEIGHT CLASS E *X-Y-Z	TOTALS * (T)	TOTALS * X-Y-Z
I. SEVERE IMPACT					(70)	37-9-24
A. Controlled Collision	6-1-1	10-1-0	7-1-0	0-1-0	(28)	23-4-1
B. Uncontrolled Collision	3-0-0	2-2-1	2-0-0	1-0-0	(11)	8-2-1
C. Undershoot	1-0-12	2-2-4	1-0-2		(24)	4-2-18
D. Stall	1-0-3	1-1-1			(7)	2-1-4
II. MODERATE-HIGH SINK SPEED					(154)	8-12-134
A. Hard Landing	1-0-6	1-0-12	0-1-5	0-0-1	(27)	2-1-24
B. Gear Collapse	0-2-17	0-1-13	1-0-8		(42)	1-3-38
C. Wheels Up	0-0-10	0-0-5	0-0-1		(16)	0-0-16
D. Retracted Gear	0-0-11	0-0-3			(14)	0-0-14
E. Swerve	0-1-12	0-1-8	1-0-4	0-0-2	(29)	1-2-26
F. Overshoot	0-2-6	2-3-5	2-[illegible]	0-0-1	(26)	4-6-16
III. SYSTEM MALFUNCTION					(80)	8-15-57
A. Engine Malfunction	1-3-14	1-2-9	0-3-2	0-1-2	(36)	2-9-27
B. Prop/Rotor Malfunction	3-0-2	1-0-1			(7)	4-0-3
C. Airframe Failure	1-1-3	0-0-4	0-1-2	0-1-3	(16)	1-3-12
D. Fire/Explosion	1-0-5	0-0-5	0-2-4	0-1-1	(26)	1-3-15
IV. COLLISION WITH					(37)	10-6-21
A. Trees	3-0-3	3-0-1			(10)	6-0-4
B. Ditches Fence Seawall	0-1-0	1-2-0	1-0-0		(5)	2-3-0
C. App. Lights Wires	0-0-1	0-2-3	0-0-3	0-1-0	(10)	0-3-7
D. Obstacles (Bldg. Auto)	1-0-5	0-0-3	1-0-1	0-0-1	(12)	2-0-10
TOTALS	22-11-111	24-17-78	16-9-36	1-5-11	341	63-42-236
	144 (42%)	119 (35%)	61 (18%)	17 (5%)	341	

*X-Y-Z X = NO. OF ACCIDENTS INVOLVING FATALITIES
Y = NO. OF ACCIDENTS IN WHICH HIGHEST INJURY INDEX IS SEVERE INJURY
Z = NO. OF ACCIDENTS IN WHICH ONLY MINOR/NO INJURIES WERE SUSTAINED

(T) = TOTAL NO. OF ACCIDENTS

TABLE 5. - AVERAGE DISTANCE FROM AIRPORT ASSOCIATED WITH ACCIDENT CATEGORIES

DESCRIPTION	AVERAGE DISTANCE FROM AIRPORT (MILES)
HARD LANDING	0.00
CONTROLLED COLLISION	7.80
UNCONTROLLED COLLISION	2.70
UNDERSHOOT	.16
STALL	1.20
COLLISION WITH OBSTACLE (ALL)	(1.50)
a) OFF AIRPORT	2.30
b) AT AIRPORT	0.00
ABORTED TAKEOFF	.13
OVERSHOOT	.11

TABLE 6. - SUMMARY OF ACCIDENT OCCURRENCE AS A FUNCTION OF PROXIMITY TO AIRPORT

1964-69 NTSB Data	SEVERITY OF INJURY			TOTAL No. OF ACCIDENT RECORDS	% TOTAL
LOCATION	FATAL	SERIOUS	MINOR/NONE		
On airport	12	33	180	225	50.34
Within: 1/4 Mile	0	2	3	5	1.12
1/2 Mile	2	1	1	4	.89
3/4 Mile	1	1	1	3	.67
1 Mile	1	1	3	5	1.12
2 Miles	5	2	2	9	2.01
3 Miles	2	2	1	5	1.12
4 Miles	2	0	0	2	.45
5 Miles	3	0	3	6	1.34
Beyond 5 miles	35	101	24	160	35.79
In traffic pattern unknown	5	5	6	16	3.58
Miscellaneous	0	4	3	7	1.57
Totals	68	152	227	447	100.

TABLE 7. - COMPARATIVE SUMMARY OF ACCIDENT TYPES BY AIRPLANE WEIGHT CLASS, FOR NTSB AND WORLDWIDE DATA

NTSB 1964-77 Data	WEIGHT CLASS				TOTALS*	
	B* X-Y-Z	C* X-Y-Z	D* X-Y-Z	E* X-Y-Z	(T)	X-Y-Z
I. SEVERE IMPACT					(70)	37-9-24
A. Controlled Collision	6-1-1	10-1-0	7-1-0	0-1-0	(28)	23-4-1
B. Uncontrolled Collision	3-0-0	2-2-1	2-0-0	1-0-0	(11)	8-2-1
C. Undershoot	1-0-12	2-2-4	1-0-2		(24)	4-2-18
D. Stall	1-0-3	1-1-1			(7)	2-1-4
II. MODERATE-HIGH SINK SPEED					(154)	8-12-134
A. Hard Landing	1-0-6	1-0-12	0-1-5	0-0-1	(27)	2-1-24
B. Gear Collapse	0-2-17	0-1-13	1-0-8		(42)	1-3-38
C. Wheels Up	0-0-10	0-0-5	0-0-1		(16)	0-0-16
D. Retracted Gear	0-0-11	0-0-3			(14)	0-0-14
E. Swerve	0-1-12	0-1-8	1-0-4	0-0-2	(29)	1-2-26
F. Overshoot	0-2-5	2-3-5	2-1-4	0-0-1	(26)	4-6-16
TOTALS	12-6-78 96	18-11-52 81	14-3-24 41	1-1-4 6	(224)	45-21-158
Worldwide 1964-79** Data						
I. SEVERE IMPACT					(210)	115-16-79
A. Controlled Collision	49-7-24	6-1-6	3-0-4		(100)	58-8-34
B. Uncontrolled Collision	12-2-7	11-1-1	4-0-2		(40)	27-3-10
C. Undershoot	5-3-11	4-0-5	5-1-1	0-0-2	(37)	14-4-19
D. Stall	12-1-13	1-0-3	2-0-0	1-0-0	(33)	16-1-16
II. MODERATE-HIGH SINK SPEED					(450)	18-29-403
A. Hard Landing	1-0-15	0-0-18	1-0-12	0-0-4	(51)	2-0-49
B. Gear Collapse	3-5-92	1-1-36	0-0-11	0-0-3	(152)	4-6-142
C. Wheels Up	0-0-27	0-0-0	0-0-0	0-0-0	(27)	0-0-27
D. Retracted Gear	0-8-28	0-1-14	0-0-4	0-0-2	(57)	0-9-48
E. Swerve	0-8-28	2-1-10	1-1-5	0-0-1	(88)	8-4-76
F. Overshoot	1-6-30	3-3-19	0-1-7	0-0-5	(75)	4-10-61
TOTALS	88-34-307 429	28-8-112 148	16-3-46 65	1-0-17 18	(660)	133-45-482

* X-Y-Z

X = No. of accidents involving fatalities

Y = No. of accidents in which highest injury index is severe injury

Z = No. of accidents in which only minor/no injuries were sustained

** Thru March 1979 (T) = Total No. of Accidents

ORIGINAL PAGE IS
OF POOR QUALITY

TABLE 8. - COMBINED SELECTED ACCIDENT DATA BASE (REF. 19, 20, 21)

(a) Takeoff
(b) Climb
(c) Approach
(d) Landing
(e) Taxi

(a) Takeoff

Date	A/C	Location	Hull Loss	Onboard	Fatal	Serious Injury	Flight Phase	Fire	Impact Survivable	Water Landing	Description
011961	DC8	JFK	X	106	4	?	TO	FIRE	PAR		ABORTED AT V1-OVERRAN-HIT BLAST FENCE-CROSSED BLVD-KILLED FLT DECK CREW
072761	707	HAMBURG	X	41	0	10	TO	FIRE	YES		VEERED OFF RUNWAY-SEPARATED GEAR, #2 & #3 ENG. BROKE FUSE-FIRE BOTH WINGS
060362	707	PARIS, ORLY	X	132	130	2	TO	FIRE	UDF		OVERRUN-BRAKE FIRE-LMG SEP.-FIRE LT WING-RMG SEP.-#2 END SEP.-TWR, BLG
082062	DC8	RIO DE JANIERO	X	105	15	?	TO		YES	WAT	ABORTED-OVERRUN-LOST THRUST REVERSERS-HIT FENCE, ROAD-ENTER WATER-DROWNINGS
112364	707	ROME	X	73	48	20	TO	FIRE	YES		ABORTED-VEERED OFF RUNWAY-HIT STREAM ROLLER AND LOST #4 ENG-FUEL FIRE, EXPLOSION
070466	DC8	AUCKLAND	X	5	2	1	TO	FIRE	PAR		ENGINE OUT TRAINING-RT. WING HIT GRD-A/C BROKE UP
082666	880	TOKYO	X	5	5	0	TO	FIRE	YES		ENGINE OUT TRAINING-VEERED OFF RUNWAY-HIT DITCH-LOST GEAR, ENGINES-WING FIRE
110667	707	CINCINNATI	X	36	1	2	TO	FIRE	PAR		ABORTED AT V1-OVERRAN-LOST MAIN GEAR-A/C DAMAGED IN SLIDE OUT-WING BREAK-FIRE
110567	880	HONG KONG	X	137	1	?	TO		YES	WAT	ABORT-VEERED OFF RUNWAY INTO BAY-FUSELAGE BROKE & SANK-DROWNING
122768	DC9	SIOUX CITY	X	66	0	3	TO		YES		ABORTED AT V1-SLID OFF RUNWAY INTO TREES
032168	727	CHICAGO	X	3	0	1	TO	FIRE	YES		ABORTED AT VR-OVERRAN-HIT DITCH-BROKE LT. WING, FUSELAGE-#4 ENG. SEP.
011469	BAC	MILAN	X	33	0	0	TO		YES		LOST POWER AT VR-WHEELS UP LDG.-SLID INTO TREES
071970	737	PHILADELPHIA	X	62	0	1	TO		YES		LOST POWER-OVERRAN-GEAR FAILED, #1 ENG. SEP, #1 TANK RUPTURED
112770	DC8	ANCHORAGE	X	229	47	47	TO	FIRE	YES		ABORTED-HIT DITCH AND ANTENNA TOWER-A/C LOST PARTS-FUSE. BROKE-FIRE
020970	CMT	MUNICH	X	23	0	0	TO	FIRE	YES		ABORTED-HIT FENCE-GEAR SEP.-FIRE IN RT. WING
071970	BAC	GERONA, SPAIN	X	85	0	3	TO		YES		ABORTED-OVERRAN-HIT 20 FT. HIGH EMBANKMENT
113070	707	TEL AVIV	X	3	0	0	TO	FIRE	YES		HIT A/C UNDER TOW-LOST ENGINES AND GEAR IN SLIDE OUT
012371	707	BOMBAY	X	5	0	0	TO	FIRE	YES		ENGINE OUT TRAINING-LOST POWER-TAIL HIT RUNWAY-VEERED INTO ROUGH TERRAIN
122072	DC9	CHICAGO O'HARE	X	45	10	9	TO	FIRE	YES		HIT CV880-IMPACTED RUNWAY-SKIDDED 800 FT.-FIRE IN RUPTURED FUEL LINES
041772	VC1	ADDIS ABABA	X	107	43	?	TO	FIRE	UDF		LOST POWER-ABORTED-OVERRAN-OVER STEEP BANK-HIT ILS TOWER-IMPACTED GRD.
081372	707	JFK		186	0	0	TO	FIRE	YES		ABORTED-OVERRAN-HIT BLAST FENCE-BROKE LT. WING-FIRE
030573	707	DENVER		3	0	0	TO	FIRE	YES		3 ENG FERRY FLT-LT. WING HIT GRD-A/C VEERED OFF RUNWAY
121773	DC9	GREENSBORO		91	0	0	TO	FIRE	YES		LOST POWER-ABORTED-VEERED OFF RUNWAY-LMG FOLDED-LT. WING TANK RUPTURED
020975	BAC	LAKE TAHOE	X	44	0	0	TO		YES		HIT SNOW BANK-VEERED OFF RUNWAY-RT. WING, RMG, NG SEPARATED
111275	DC1	JFK	X	139	0	2	TO	FIRE	YES		ENGINE DISINTEGRATED-ABORTED-FIRE #3 ENG-WENT OFF TAXIWAY-RT. WING LOST FUEL
121676	880	MIAMI	X	3	0	1	TO		YES		FWD CG-ABORTED-OVERRUN-STOPPED IN CANAL
111676	DC9	DENVER	X	85	0	2	TO	FIRE	YES		STALL AT VR-ABORTED-VEERED OFF RUNWAY-HIT DITCHES AND POLES-TANK RUPTURE
031777	707	PRESTWICK	X	4	0	0	TO	FIRE	YES		ENGINE OUT TRAINING-LARGE YAW & ROLL-A/C HIT GRD-SLID OUT LOSING GEAR & ENGINE
032777	747	TENERIFE	X	246	246	0	TO	FIRE	YES		A/C HIT PAA 747-LOST LMG AND #2 ENG.-HIT RUNWAY AND BURNED
100277	DC8	SHANNON	X	259	0	1	TO	FIRE	YES		WHEEL FAILURE-ABORTED-RT. MAIN TANK PUNCTURE-FUEL FED FIRE
041877	DC8	TOKYO	X	140	0	0	TO		YES		VEERED OFF RUNWAY-LOST ALL GEAR AND ENGINES
030178	DC1	LOS ANGELES	X	197	2	31	TO	FIRE	YES		ABORTED AT V1-OVERRUN-LMG SEP., RUPTURED TANKS
052578	880	MIAMI	X	6	0	0	TO		YES		FWD G.C. PROBLEM-A/C OVERRUN AND BROKE UP
062678	DC9	TORONTO	X	107	2	?	TO		PAR		LOST POWER-OVERRAN-CRASHED INTO 51 FT DEEP RAVINE
121778	737	HYDERABAD, INDIA	X	126	1	4	TO	FIRE	YES		A/C STALLED-ABORTED WHEELS UP-SEPARATED BOTH ENG-FIRE STARTED LT. WING

(a) Takeoff

	Date	A/C	Location	Hull Loss	Onboard	Fatal	Serious Injury	Flight Phase	Fire	Impact Survivable	Description
	122668	707	ANCHORAGE, ALASKA	X				TO			CRASHED JUST AFTER LIFT OFF-SEVERE LATERAL DIVERGENT OSCILLATIONS WITH RT. WING
	091372	707	SAN FRANCISCO, CA	X	3	0	0	TO		YES	CAME TO REST IN BAY WATER-274 M OVERRUN
	062073	DC8	BANGOR, ME		258	0	3	TO	FIRE	YES	WET RUNWAY-A/C STOPPED ON THE RUNWAY
	032774	DC8	ALASKA		230	0	1	TO	FIRE	YES	TIRES BLEW-STOPPED 122 M SHORT OF DEPARTURE END
	082775	CL44	MIAMI, FL	X	10	6	4	TO	FIRE	YES	A/C LEFT RUNWAY INTO SOD-HIT APPROACH LIGHT STRUC.-THROUGH A DITCH, OVER A ROAD
	011677	DC8	BALTIMORE, MD		94	0	7	TO		YES	ON THE RUNWAY
**	011383	737	DC	X	79	74	5	TO		PAR	A/C STRUCK BRIDGE ABUTMENT WITH TAIL-IMPACTED INTO WATER, SANK-ICE, SLEET AND SNOW HAMPERED RESCUE OPERATIONS

N = 42

** This accident was added later and data was used in the present paper.

TABLE 8. - CONTINUED

(a) Takeoff
(b) Climb
(c) Approach
(d) Landing
(e) Taxi

(b) Climb

	HULL LOSS	ONBOARD	FATAL	SERIOUS INJURY	FLIGHT PHASE	FIRE	IMPACT SURVIVABLE	WATER LANDING	DESCRIPTION
122161 CMT ANKARA	X	34	27	6	CLI	FIRE	UDF		STALL-HARD IMPACT FROM 450 FT. ALTITUDE
091365 880 KANSAS CITY	X	4	0	0	CLI	FIRE	YES		STALL-HARD IMPACT-ENG OUT TRAINING
040868 707 LONDON	X	127	5	?	CLI	FIRE	YES		#2 ENG DISINTEGRATED-LOST #2-FIRE-FAILED TO SHUT OFF FUEL VALVE-FIRE DEATHS
042068 707 WINDHOEK	X	128	123	5	CLI	FIRE	PAR		A/C FLEW INTO GRD-FUSELAGE BROKE-6 SURVIVORS BEHIND COCKPIT
062[illegible] 880 MOSES LAKE	X	5	3	?	CLI	FIRE	YES		ENGINE OUT-TRAINING-A/C HIT ON RT. WING-SLID 3000 FT.-FIRE
010570 990 STOCKHOLM	X	10	5	4	CLI		PAR		3 ENG FERRY FLIGHT-IMPACT TREES, GRD WITH WING-FUSELAGE AFT OF COCKPIT DESTROYED
090671 BAC HAMBURG	X	121	22	?	CLI	FIRE	UDF		LOST ALL POWER AT 165 FT-STEEP BANK-CRASHED ON AUTOBAN-HIT BRIDGE
112872 DC8 MOSCOW, USSR	X	76	62	15	CLI	FIRE	UDF		STALL DUE TO FLAP RETRACTION
010274 F28 IZMIR, TURKEY	X	72	65	7	CLI	FIRE	UDF		AT 33 FT BANKED LEFT AND CRASHED-PROBABLY STALL
112074 747 NAIROBI, KENYA	X	157	59	44	CLI	FIRE	PAR		NOSE HIGH STALL-AFT FUSELAGE HIT ELEVATED ROAD-A/C BROKE UP
080775 727 DENVER	X	134	0	15	CLI		YES		WING SHEAR-STALL
020979 DC9 MIAMI	X	5	0	1	CLI		YES		ENG OUT TRAINING-WING HIT GRD
N= 12									

TABLE 8. - CONTINUED

(a) Takeoff
(b) Climb
(c) Approach
(d) Landing
(e) Taxi

(c) Approach

Date	A/C	Location	Hull Loss	Onboard	Fatal	Serious Injury	Flight Phase	Fire	Impact Survivable	Water Landing	Description
101959	707	OSO, WASHINGTON	X	8	4	0	APP	FIRE	PAR	WAT	ATTEMPTED CRASH LDG IN RIVER-HIT TREES-FWD FUSELAGE DESTROYED
082759	CMT	ASUNCION	X	50	2	?	APP		UDF		INSTRUMENT APPROACH-TOUCHDOWN 5.5 MILES FROM RUNWAY
070363	CVL	CORDOBA, ARGENTINA	X	70	0	?	APP	FIRE	YES		SHORT-HIT TREES, TANKS RUPTURE, FIRE-HIT RAILROAD TRACKS-LOST GEAR
050265	720	CAIRO	X	127	121	6	APP	FIRE	UDF		HIGH RATE OF DESCENT-IMPACTED HILL IN LEFT TURN-SURVIVORS EJECTED
110865	727	CINCINNATI	X	62	58	4	APP	FIRE	PAR		IMPACTED WOODED HILL-A/C BROKE UP
030466	DC8	TOKYO	X	72	64	8	APP	FIRE	UDF		WINDSHEAR-A/C HIT APPROACH LIGHTS AND SEAWALL-SURVIVORS EJECTED
063066	TPI	KUWAIT	X	83	0	0	APP		YES		LANDED IN SANDY SOIL-SEPARATED GEAR-MINOR FUEL SPILL
122466	DC8	MEXICO CITY	X	110	0	6	APP	FIRE	YES		LANDED IN DRY LAKE BED-HIT 3 FT HIGH ROAD, SHED N.G.-FUSELAGE BROKE
021566	CVL	NEW DELHI	X	81	2	14	APP	FIRE	YES		A/C HIT CEMENT PILLAR-GEAR FAILED-WING TANKS RUPTURED-FIRE
112067	880	CINCINNATI	X	82	70	12	APP	FIRE	PAR		IMPACTED WOODED HILL-A/C BROKE UP
030567	DC8	MONROVIA	X	90	51	23	APP	FIRE	UDF		HIGH RATE OF DESCENT-LOST ENGINES AND GEAR-HIT SEVERAL HOUSES-FIRE
063067	CVL	HONG KONG	X	80	17	5	APP		YES	WAT	SHORT, IN WATER, NOSE UP-A/C FUSELAGE BROKE-A/C SANK-PAX DROWNED
061368	707	CALCUTTA	X	63	6	2	APP	FIRE	YES		SHORT-HIT TREES AND HOUSE TOPS-LOST GEAR AND 3 ENGINES-FUEL LEAK-FIRE
021668	727	TAIPEI	X	63	21	42	APP	FIRE	UDF		SHORT-HIT TREES, FARM HOUSE, MORE TREES-A/C BROKE UP AND BURNED
080268	DC8	MILAN	X	95	12	?	APP	FIRE	YES		WINDSHEAR-MILD IMPACT ON HILL WITH TREES-A/C INTACT-FUEL SPILL, ENGINE FIRE
010569	727	LONDON GATWICK	X	65	50	14	APP	FIRE	PAR		SHORT-HIT TREES, HOUSE A/C DISINTEGRATED IN SLIDE OUT-FIRE
011369	DC8	LOS ANGELES	X	45	15	17	APP		YES	WAT	IMPACT SANTA MONICA BAY-A/C FUSELAGE BROKE AND SANK-PAX DROWNED
092169	727	MEXICO CITY	X	118	28	78	APP		PAR	WAT	IMPACT SHORT IN SHALLOW LAKE-SLID 900 FT AND HIT 10 FT HIGH RR BED-A/C BROKE UP
091269	BAC	MANILA	X	47	45	2	APP	FIRE	PAR		HIT HILL-SURVIVORS EJECTED
072770	DC8	NAHA, OKINAWA	X	4	4	0	APP		PAR	WAT	IMPACTED WATER-A/C BROKE UP-2 CREW TRAPPED IN COCKPIT DROWNED
033170	CVL	CASABLANCA	X	82	61	21	APP	FIRE	UDF		A/C HIT POWER LINES, IMPACTED ON HIGHWAY-BOUNCED IN BALL OF FLAME-FUSELAGE BROKE
120770	BAC	CONSTANA	X	27	18	?	APP		UDF		SHORT
120872	737	CHICAGO MIDWAY	X	61	43	12	APP	FIRE	PAR		STALLED-IMPACTED HOUSES AND TREES-A/C BROKE UP-FIRE
122972	L10	MIAMI	X	176	99	60	APP	FIRE	PAR	WAT	IMPACTED IN EVERGLADES-A/C DISINTEGRATED-MOST SURVIVORS EJECTED
012172	DC9	ADANA	X	5	1	?	APP	FIRE	YES		IMPACTED ON DOWNWIND LEG AND BURNED
122372	F28	OSLO	X	45	40	?	APP	FIRE	UDF		A/C IMPACTED IN FOREST-DISINTEGRATED AND BURNED
073173	DC9	BOSTON, MASS.	X	89	89	0	APP	FIRE	PAR		A/C HIT SEAWALL AND DISINTEGRATED AND BURNED
112773	DC9	CHATTANOOGA	X	77	0	5	APP	FIRE	YES		HIT APPROACH LIGHTS-LT. WING, ENGINE AND GEAR SEPARATED-FUSELAGE BROKE
053173	737	NEW DELHI	X	65	52	?	APP	FIRE	YES		SHORT-HIT BOULDERS-SEP GEAR, RT WING, #2 ENGINE-FUSELAGE BROKE AND BURNED
060973	707	RIO DE JANEIRO	X	4	2	0	APP		PAR	WAT	INADVERTENT SPOILERS-A/C HIT APPROACH LIGHTS-IMPACTED WATER
011374	707	PAGO PAGO, AM. SAMOA	X	101	97	5	APP	FIRE	YES		A/C HIT TREES, LAVA WALL, AND DITCH-TANKS RUPTURED-FIRE
091174	DC9	CHARLOTTE, N.C.	X	82	71	10	APP	FIRE	PAR		A/C LANDED IN FIELD, HIT TREES-SEPARATED GEAR AND WINGS-IMPACTED GULLEY-FIRE
010174	F28	TURIN, ITALY	X	42	38	4	APP	FIRE	UDF		IMPACT SHORT-FUSELAGE BROKE AND BURNED
062475	727	JFK	X	124	112	12	APP	FIRE	PAR		WINDSHEAR-HIT APPROACH LIGHTS-A/C BROKE UP
111275	727	RALEIGH, N.C.		139	0	1	APP		YES		WINDSHEAR-HARD IMPACT
111575	F28	NR. BUENOS AIRES	X	66	0	0	APP		YES		A/C HIT TREE-LOST GEAR AND LT. WING TIP ON GRD IMPACT-HIT LARGE TREE
042276	720	BARRANQUILLA, COL.	X	4	0	1	APP	FIRE	YES		A/C HIT TREES-LOST BOTH WINGS-FUSELAGE BROKE
030477	DC8	NIAMEY, NIGER	X	4	2	2	APP	FIRE	YES		SHORT-HIT DITCHES-A/C BROKE UP IN SLIDE
040477	DC9	NEW HOPE, GA.	X	85	62	22	APP	FIRE	PAR		LANDED ON HIGHWAY-HIT TREES, POLES, CARS, BUILDINGS, FUSELAGE BROKE-FIRE
092777	DC8	KUALA LUMPUR	X	79	34	?	APP	FIRE	UDF		CRASHED ON RUBBER PLANTATION
112177	BAC	BARILOCHE, ARG.	X	79	45	34	APP		UDF		IMPACTED ROCKEY AREA
121877	CVL	MADEIRA	X	57	36	13	APP		YES	WAT	A/C TOUCHED DOWN IN WATER-FLOATED 5 MINUTES-PAX DROWNED
050878	727	PENSACOLA	X	58	3	11	APP		YES	WAT	IMPACTED WATER IN APPROACH ATTITUDE-PAX DROWNED
111578	DC8	COLUMBO, SRI LANKA	X	259	195	?	APP	FIRE	UDF		CRASHED IN THUNDERSTORM-HIT COCONUT TREES-MOST SURVIVORS FROM AFT SECTION
122978	DC8	PORTLAND, OREGON	X	186	10	23	APP		PAR		RAN OUT OF FUEL-HIT POLES, BANKS, HOUSES, TREES-FWD FUSELAGE CRUSHED
021979	707	ST. LUCIA		170	0	0	APP		YES		HARD IMPACT-FUSELAGE FLOOR DISTORTED
031479	727	DOHA, QATAR	X	64	45	15	APP	FIRE	PAR		WINDSHEAR-HARD TAIL DOWN IMPACT-HIT BLDG

ORIGINAL PAGE IS OF POOR QUALITY

TABLE 8. - CONTINUED

(a) Takeoff
(b) Climb
(c) Approach
(d) Landing
(e) Taxi

(c) Approach (continued)

			HULL LOSS	ONBOARD	FATAL	SERIOUS INJURY	FLIGHT PHASE	FIRE	IMPACT SURVIVABLE	WATER LANDING	DESCRIPTION
042266	L-188	ARDMORE, OK	X	98	83	15	APP	FIRE	PAR		ENV>>10 M/SEC-FWD SECTION TELESCOPED-SURVIVORS WERE IN MID AND AFT COMP'TS A/C FLEW INTO HILL
080768	727	BOSTON	X	83	0	0	APP		YES		A/C LANDED-61 M SHORT
122468	CV580	BRADFORD, PA	X	47	20	12	APP	FIRE	PAR		IMPACTED TREES-A/C BROKE UP AS IT CUT THE TREES AND ROLLED TO AN INVERTED POSITION BEFORE STRIKING GRD
122768	CV580	CHICAGO, IL	X	45	27	16	APP	FIRE	PAR		A/C STRUCK HANGER IN INVERTED POSITION-FWD (ROWS 1-5) NONSURVIV-ROWS 6-7 QUESTIONABLE-ROWS 8-12 SURVIVABLE
010669	CV580	BRADFORD, PA	X	29	11	17	APP	FIRE	PAR		A/C CUT THROUGH TREES AND CAME TO REST INVERTED-BREAKUP PROGRESSED-OCCURRED 7563 M FROM AIRPORT
100270	M404B	SILVER PLUME, CO	X	40	30	10	APP	FIRE	PAR		INCLINE IN EXCESS OF 28°-(ENV>33.6 M/SEC)-DESCENDED THROUGH TREES 12876 M FROM AIRPORT
060771	CV440	NEW HAVEN, CT	X	31	28	3	APP	FIRE	YES		A/C HIT COTTAGES-OCCURRED 1609 M FROM AIRPORT
030372	FH227	ALBANY, NY	X	48	16	32	APP		PAR		A/C CRASHED INTO HOUSE AND CAME TO REST WITHIN CONFINES OF THE RESIDENCE
053072	DC9	FORT WORTH, TX	X	4	4	0	APP	FIRE	PAR		FOLLOWED IN WAKE OF DC-10-NONSURVIVAL FOR COCKPIT CABIN COMP'T INTERITY MAINTAINED-A/C INVERTED ON RUNWAY
072373	FH227	ST LOUIS, MO	X	44	38	6	APP	FIRE	NON		CRASHED IN RESIDENTIAL AREA SURROUNDED BY TREES-CABIN TORE OPEN BY TREES-OCCURRED 3700 M FROM AIRPORT
083075	F27	ALASKA	X	32	10	20	APP	FIRE	PAR		HIGH ENV DUE TO STEEP MOUNTAIN INCLINE 25°-A/C OVERTURNED AFTER IMPACT-OCCURRED 2414 M FROM AIRPORT
020876	DC6	VAN NUYS, CA	X	6	3	0	APP	FIRE	PAR		CRASHED 1609 M SHORT OF RUNWAY ONTO GOLF COURSE AND HIT BUILDING
102077	CV240	MS	X	26	6	19	APP		PAR		A/C CRASHED IN HEAVILY WOODED AREA-COCKPIT NONSURVIVABLE-CABIN SURVIVABLE-OCCURRED 6547 M FROM AIRPORT

N = 59

(d) Landing

			HULL LOSS	ONBOARD	FATAL	SERIOUS INJURY	FLIGHT PHASE	FIRE	IMPACT SURVIVABLE	WATER LANDING	DESCRIPTION
022060	CMT	BUENOS AIRES	X	6	0	0	LDG	FIRE	YES		HARD IMPACT-GEAR FAILED LOST POD TANKS-FIRE-TRAINING
071161	DC8	DENVER	X	122	17	0	LDG	FIRE	YES		HYDRAULICS FAILED-A/C VEERED OFF RUNWAY-HIT TRUCK-LOST ALL GEAR, ENG. 1,2,4-BURNED
061561	707	LISBON		103	0	2	LDG	FIRE	YES		HARD LDG-COLLAPSE NOSE GEAR
092761	720	BOSTON		71	0	2	LDG		YES	WAT	LONG, HARD LANDING-GEAR COLLAPSE FRICTION FIRE-TANKS LEAKED
092761	CVL	BRASSILA	X	?	?	?	LDG	FIRE	UDF		SHORT, HARD LANDING-GEAR COLLAPSE FRICTION FIRE-TANKS LEAKED
031864	BAC	WISLEY, ENG.		5	0	1	LDG		YES		HARD LANDING-SEPARATED ONE ENGINE, NOSE & RMG
040764	707	JFK	X	145	0	7	LDG		YES	WAT	OVERRUN-ENTERED THURSTON BASIN
032264	CMT	SINGAPORE	X	86	0	0	LDG	FIRE	YES		LNG FAILED-A/C STOPPED ON REMAINING GEAR AND LEFT WING TIP-FIRE
070165	707	KANSAS CITY	X	66	0	2	LDG		YES		GRD LOOP ON OVERRUN-HIT BLG, LEVEE
111165	727	SALT LAKE CITY	X	91	43	35	LDG	FIRE	YES		HIGH RATE OF DESCENT-GEAR FAILURE-FUEL LINE FIRE
022765	880	IKI IS., JAPAN	X	6	0	2	LDG	FIRE	YES		SHORT-GEAR SHEARED ON RUNWAY LIP-RUPT TANK-FIRE
092967	CMT	ROME	X	66	0	0	LDG		YES		HARD LDG-VEERED OFF RUNWAY-HIT CONCRETE BOX-FUEL SPILL
032868	DC8	ATLANTIC CITY	X	4	0	2	LDG	FIRE	YES		2 ENG OUT TRAINING-VEERED OFF RUNWAY HIT DITCH-LOST GEAR-ENG FIRE
060368	727	JFK		102	0	4	LDG		YES		HIT ILS TOWER-LOST GEAR
020768	707	VANCOUVER, B.C.	X	61	1	0	LDG		PAR		VEERED OFF RUNWAY-HIT BLG
101669	DC8	STOCKTON, CA	X	5	0	0	LDG	FIRE	YES		OVERRUN-HIT DITCH-LOST GEAR, ENGINE-FUEL SPILL
021170	707	STOCKTON, CA		6	0	1	LDG		YES		VEERED OFF RUNWAY-HIT DITCH-LOST NOSE GEAR-FRACTURED WING
092870	DC9	LOUISVILLE		94	0	0	LDG	FIRE	YES		SHORT ON 5° SLOPE-BROKE FUSELAGE-BOUNCED ONTO RUNWAY
122870	727	ST. THOMAS	X	55	2	11	LDG	FIRE	YES		HARD IMPACT-BOUNCED-OVERRUN-HIT TRUCK-SLIDE UP HILL-A/C BROKE UP
080870	990	ACAPULCO	X	8	0	8	LDG	FIRE	YES		HARD IMPACT-FAILED WINGS
050270	DC9	ST. CROIX, V.I.	X	63	25	25	LDG		PAR	WAT	IMPACT WATER-PAX DROWNED
070570	DC8	TORONTO	X	108	108	0	LDG	FIRE	YES		HARD-TAIL FIRST-#4 ENG HIT RUNWAY, SEPARATED-FIRE-EXPLOSION ON GO AROUND
091570	DC8	JFK	X	156	0	?	LDG	FIRE	YES		HARD LDG.
121571	707	URUNCHI, CHINA	X	3	0	0	LDG		YES		HARD LDG.
051872	DC9	FT. LAUDERDALE	X	10	0	3	LDG	FIRE	YES		HARD LDG.-GEAR SEP. & TANK RUPT.
092472	DC8	BOMBAY	X	120	0	0	LDG	FIRE	YES		RUNWAY TOO SHORT-OVERRUN HIT DITCH
121572	747	MIAMI	X	160	0	0	LDG		YES		OVERRUN-HIT CONCRETE BLG. FOUNDATION
122872	F28	BOLBAO, SPAIN	X	4	0	4	LDG		YES		OVERRUN-CROSSED GULLY AND STREAM
112773	DC9	AKRON, OHIO	X	26	0	16	LDG		YES		OVERRUN-FELL INTO 50 FT. DEEP RAVINE
012273	707	KHANO, NIGERIA	X	202	172	?	LDG	FIRE	YES		SHORT-HARD-LOST RMG-LEFT WING SEPARATED-FIRE AT ROOF-FIRE DEATHS
102873	737	GREENSBORO		96	0	0	LDG	FIRE	YES		OVERRUN TO SMALL HILL
061673	707	BUENOS AIRES		86	0	0	LDG	FIRE	YES		HARD LDG.-WING HIT GRD. & SEPARATED-FIRE

TABLE 8. - CONCLUDED

(a) Takeoff
(b) Climb
(c) Approach
(d) Landing
(e) Taxi

(d) Landing (continued)

Date	A/C	Location	Hull Loss	Onboard	Fatal	Serious Injury	Flight Phase	Fire	Impact Survivable	Water Landing	Description
062373	DC8	JFK		128	0	8	LDG	FIRE	YES		INADVERTANT SPOILER DEPLOYMENT-HARD LANDING
121773	DC1	BOSTON	X	151	0	3	LDG	FIRE	YES		A/C HIT APPROACH LIGHTS-LDG. & GEARS
121973	707	NEW DELHI	X	109	0	3	LDG	FIRE	YES		A/C HIT MIDDLE MARKER BLG.
122373	CVL	MANAUS, BRAZIL	X	57	0	1	LDG		YES		OVERRUN-WENT DOWN A SLOPE TO 50 FT. BELOW RUNWAY
011674	707	LOS ANGELES	X	63	0	3	LDG	FIRE	YES		HARD-NOSE DOWN IMPACT-NO FLARE
091174	727	PORTO ALEGRE, BRAZIL		74	0	0	LDG		YES		LONG AND FAST-WENT THROUGH 2 BRICK WALLS
033175	737	CASPER, WYO.	X	99	0	1	LDG		YES		OVERRUN-HIT ILS-DITCH
092475	F28	PALEMBANG	X	62	25	?	LDG	FIRE	UDF		OVERRUN-HIT TREES
010276	DC1	ISTANBUL	X	373	0	1	LDG	FIRE	YES		SHORT-LOST GEAR, ENGS.-LEFT WING SEP.
040576	727	KETCHIKAN	X	57	1	32	LDG	FIRE	PAR		OVERRUN-FLEW OVER GULLY-LANDED IN RAVINE-WING FIRE-FUEL LEAK
042776	727	ST. THOMAS, V.I.	X	88	37	19	LDG	FIRE	PAR		OVERRUN-WENT DOWN SLOPE, CROSSED ROAD-HIT GAS STATION-FUSELAGE BROKE-FIRE
062376	DC9	PHILADELPHIA	X	105	0	36	LDG		YES		WHEELS UP-TRAIL FIRST-SLID OFF RUNWAY
111977	727	MADEIRA	X	164	128	36	LDG	FIRE	PAR	WAT	OVERRUN-SLID DOWN 75° EMBANKMENT-HIT BRIDGE-FUEL SPILL-SURVIVORS EJECTED
111777	747	JFK		3	0	0	LDG		YES		VEERED OFF RUNWAY
021178	737	CRANBROOK, B.C.	X	49	42	5	LDG	FIRE	PAR		ABORTED LDG-ATTEMPTED GO ROUND-A/C HIT LT. WING & NOSED DOWN
030378	DC8	SANTIAGO DE COMPO.	X	222	0	52	LDG		YES		OVERRUN WENT DOWN 65' EMBANKMENT
040278	737	SAO PAULO	X	42	0	0	LDG	FIRE	YES		WHEELS UP-DID NOT SHUT OFF FUEL VALVE
040478	737	CHARLROI, BELGIUM	X	3	0	0	LDG	FIRE	YES		OVERRUN-HIT ILS TOWER-TRAINING
070978	BAC	ROCHESTER		77	0	1	LDG		YES		OVERRUN-HIT DITCH
122378	DC9	PALERMO, ITALY	X	129	108	?	LDG		UDF	WAT	IMPACTED LEVEL-BROKE UP AND SANK-PAX DROWNED
032578	720	LONDON		82	0	?	LDG		YES		HIT HARD AND BOUNCED-NOSE GEAR COLLAPSED
042679	737	MADRAS	X	67	0	8	LDG	FIRE	YES		OVERRUN-ROUGH TERRAIN-SEP. ENG. & NG & RMLG. LMLG COLLAPSED-MINOR FIRE
100779	DC8	ATHENS	X	154	14	0	LDG	FIRE	YES		OVERRUN-CRACK IN LEFT WING-FIRE
103179	DC1	MEXICO CITY	X	87	70	17	LDG	FIRE	UDF		TOUCHDOWN-HIT VEH., SEP. MLG-AIRBORNE-HIT WING LOW-HIT BLG.

(d) Landing

Date	A/C	Location	Hull Loss	Onboard	Fatal	Serious Injury	Flight Phase	Fire	Impact Survivable	Water Landing	Description
060868	727	SALT LAKE CITY		92	0	4	LDG		YES		SLID OFF RUNWAY-YAWING TO LEFT, @ 100° ANGLE TO THE RUNWAY
081269	DC9	VIRGIN ISLANDS, V.I.		119	0	0	LDG		YES		ENCOUNTERED RAISED SIDEWALK-CAME TO REST PENETRATING A METAL BLG-100 M OVERRUN

N = 59

(e) Taxi

Date	A/C	Location	Hull Loss	Onboard	Fatal	Serious Injury	Flight Phase	Fire	Impact Survivable	Water Landing	Description
031574	CVL	TEHRAN, IRAN	X	96	15	?	TAX	FIRE	YES		GEAR COLLAPSED-WING HIT GRD-FIRE
121675	747	ANCHORAGE		121	0	2	TAX		YES		SLIDE BACKWARDS OFF RUNWAY-HIT BANK
032777	747	TENERIFE	X	396	334	62	TAX	FIRE	PAR		COLLISION WITH KLM 747-WING RUPTURE-FUSELAGE CRUSHED-FIRE

(e) Taxi

Date	A/C	Location	Hull Loss	Onboard	Fatal	Serious Injury	Flight Phase	Fire	Impact Survivable	Water Landing	Description
090172	747	JFK	X	347	0	8	TAX	FIRE	YES		A/C HAD 2 FLAT LNG GEAR TIRE-ENG. NOT SHUTDOWN PRIOR TO EVACUATION

N = 4

TABLE 9. - ACCIDENT DATA BASE SUMMARY; REF. 19

	CASES	%
TOTAL ACCIDENTS	153	100.0
FOREIGN	91	59.5
U. S. AND POSSESSIONS	62	40.5
HULL LOSS	133	87
FATALITIES OR SERIOUS INJURY	119	73
FIRE	103	67
FIRE CAUSED FATALITIES	57	37
TRAUMA CAUSED FATALITIES	55	35
DROWNING	10	6
SPECIAL	4	2.6
TRAUMA CAUSED SERIOUS INJURIES	92	60
FIRE/ SMOKE CAUSED SERIOUS INJURIES	46	30

TABLE 10. - SELECTED ACCIDENT DATA BASE (REF. 19)

(a) Takeoff
(b) Climb
(c) Approach
(d) Landing
(e) Taxi

(a) Takeoff

			HULL LOSS	ONBOARD	FATAL	SERIOUS INJURY	FLIGHT PHASE	FIRE	IMPACT SURVIVABLE	WATER LANDING	DESCRIPTION
011961	DC8	JFK	X	106	4	?	TO	FIRE	PAR		ABORTED AT V1-OVERRAN-HIT BLAST FENCE-CROSSED BLVD-KILLED FLT DECK CREW
072761	707	HAMBURG	X	41	0	10	TO	FIRE	YES		VEERED OFF RUNWAY-SEPARATED GEAR, #2 & #3 ENG. BROKE FUSE-FIRE BOTH WINGS
060362	707	PARIS, ORLY	X	132	130	2	TO	FIRE	UDF		OVERRUN-BRAKE FIRE-LMG SEP.-FIRE LT WING-RMG SEP.-#2 AND SEP.-TWR, BLG
082062	DC8	RIO DE JANIERO	X	105	15	?	TO		YES	WAT	ABORTED-OVERRUN-LOST THRUST REVERSERS-HIT FENCE, ROAD-ENTER WATER-DROWNINGS
112354	707	ROME	X	73	48	20	TO	FIRE	YES		ABORTED-VEERED OFF RUNWAY-HIT STREAM ROLLER AND LOST #4 ENG-FUEL FIRE, EXPLOSION
070466	DC8	AUCKLAND	X	5	2	1	TO	FIRE	PAR		ENGINE OUT TRAINING-RT. WING HIT GRD-A/C BROKE UP
082666	880	TOKYO	X	5	5	0	TO	FIRE	YES		ENGINE OUT TRAINING-VEERED OFF RUNWAY-HIT DITCH-LOST GEAR, ENGINES-WING FIRE
110667	707	CINCINNATI	X	36	1	2	TO	FIRE	PAR		ABORTED AT V1-OVERRAN-LOST MAIN GEAR-A/C DAMAGED IN SLIDE OUT-WING BREAK-FIRE
110567	880	HONG KONG	X	137	1	?	TO		YES	WAT	ABORT-VEERED OFF RUNWAY INTO BAY-FUSELAGE BROKE & SANK-DROWNING
122768	DC9	SIOUX CITY	X	66	0	3	TO		YES		ABORTED AT V1-SLIDE OFF RUNWAY INTO TREES
032168	727	CHICAGO	X	3	0	1	TO	FIRE	YES		ABORTED AT VR-OVERRAN-HIT DITCH-BROKE LT. WING, FUSELAGE-#4 ENG. SEP.
011469	BAC	MILAN	X	33	0	0	TO		YES		LOST POWER AT VR-WHEELS UP LDG.-SLID INTO TREES
071970	737	PHILADELPHIA	X	62	0	1	TO		YES		LOST POWER-OVERRAN-GEAR FAILED, #1 ENG. SEP, #1 TANK RUPTURED
112770	DC8	ANCHORAGE	X	229	47	47	TO	FIRE	YES		ABORTED-HIT DITCH AND ANTENNA TOWER-A/C LOST PARTS-FUSE. BROKE-FIRE
020970	CMT	MUNICH	X	23	0	0	TO	FIRE	YES		ABORTED-HIT FENCE-GEAR SEP.-FIRE IN RT. WING
071970	BAC	GERONA, SPAIN	X	85	0	3	TO		YES		ABORTED-OVERRAN-HIT 20 FT. HIGH EMBANKMENT
113070	707	TEL AVIV	X	3	0	0	TO	FIRE	YES		HIT A/C UNDER TOW-LOST ENGINES AND GEAR IN SLIDE OUT
012371	707	BOMBAY	X	5	0	0	TO	FIRE	YES		ENGINE OUT TRAINING-LOST POWER-TAIL HIT RUNWAY-VEERED INTO ROUGH TERRAIN
122072	DC9	CHICAGO O'HARE	X	45	10	9	TO	FIRE	YES		HIT CV880-IMPACTED RUNWAY-SKIDDED 800 FT.-FIRE IN RUPTURED FUEL LINES
041772	VC1	ADDIS ABABA	X	107	43	?	TO	FIRE	UDF		LOST POWER-ABORTED-OVERRAN- OVER STEEP BANK-HIT ILS TOWER-IMPACTED GRD.
081372	707	JFK		186	0	0	TO	FIRE	YES		ABORTED-OVERRAN-HIT BLAST FENCE-BROKE LEFT WING-FIRE
030573	707	DENVER		3	0	0	TO	FIRE	YES		3 ENG FERRY FLT-LT WING HIT GRD-A/C VEERED OFF RUNWAY
121773	DC9	GREENSBORO		91	0	0	TO	FIRE	YES		LOST POWER-ABORTED-VEERED OFF RUNWAY-LMG FOLDED-LT WING TANK RUPTURED
020975	BAC	LAKE TAHOE	X	44	0	0	TO		YES		HIT SNOW BANK-VEERED OFF RUNWAY-RT WING, RMG, NG SEPARATED
111275	DC1	JFK	X	139	0	?	TO	FIRE	YES		ENGINE DISINTEGRATED-ABORTED-FIRE #3 ENG-WENT OFF TAXIWAY-RT WING LOST FUEL
121676	880	MIAMI	X	3	0	1	TO		YES		FWD CG-ABORTED-OVERRUN-STOPPED IN CANAL
111676	DC9	DENVER	X	85	0	2	TO	FIRE	YES		STALL AT VR-ABORTED-VEERED OFF RUNWAY-HIT DITCHES AND POLES-TANK RUPTURE
031777	707	PRESTWICK	X	4	0	0	TO	FIRE	YES		ENGINE OUT TRAINING-LARGE YAW & ROLL-A/C HIT GRD-SLID OUT LOSING GEAR & ENGINE
032777	747	TENERIFE	X	24[illegible]	246	0	TO	FIRE	YES		A/C HIT PAA 747-LOST LMG AND #2 ENG.-HIT RUNWAY AND BURNED
100277	DC8	SHANNON	X	259	0	1	TO	FIRE	YES		WHEEL FAILURE-ABORTED-RT MAIN TANK PUNCTURE-FUEL FED FIRE
041877	DC8	TOKYO	X	140	0	0	TO		YES		VEERED OFF RUNWAY-LOST ALL GEAR AND ENGINES
030178	DC1	LOS ANGELES	X	197	2	31	TO	FIRE	YES		ABORTED AT V1-OVERRUN-LMG SEP., RUPTURED TANKS
052578	880	MIAMI	X	6	0	0	TO		YES		FWD G.C. PROBLEM-A/C OVERRUN AND BROKE UP
062678	DC9	TORONTO	X	107	2	?	TO		PAR		LOST POWER-OVERRAN-CRASHED INTO 51 FT DEEP RAVINE
121778	737	HYDERABAD, INDIA	X	126	1	4	TO	FIRE	YES		A/C STALLED-ABORTED WHEELS UP-SEPARATED BOTH ENG-FIRE STARTED LT WING
N=	35										

TABLE 10. - CONTINUED

(a) Takeoff
(b) Climb
(c) Approach
(d) Landing
(e) Taxi

(b) Climb

	HULL LOSS	ONBOARD	FATAL	SERIOUS INJURY	FLIGHT PHASE	FIRE	IMPACT SURVIVABLE	WATER LANDING	DESCRIPTION
122161 CMT ANKARA	X	34	27	6	CLI	FIRE	UDF		STALL-HARD IMPACT FROM 450 FT. ALTITUDE
091365 880 KANSAS CITY	X	4	0	0	CLI	FIRE	YES		STALL-HARD IMPACT-ENG OUT TRAINING
040868 707 LONDON	X	127	5	?	CLI	FIRE	YES		#2 ENG DISINTEGRATE-LOST #2,-FIRE-FAILED TO SHUT OFF FU[illegible] VALVE-FIRE DEATHS
042068 707 WINDHOEK	X	128	123	5	CLI	FIRE	PAR		A/C FLEW INTO GRD-FUSELAGE BROKE-6 SURVIVORS BEHIND COCKPIT
062469 880 MOSES LAKE	X	5	3	?	CLI	FIRE	YES		ENGINE OUT-TRAINING-A/C HIT ON RT. WING-SLID 3000 FT.-FIRE
010570 990 STOCKHOLM	X	10	5	4	CLI		PAR		3 ENG FERRY FLIGHT-IMPACT TREES,GRD WITH WING-FUSELAGE AFT OF COCKPIT DESTROYED
090671 BAC HAMBURG	X	121	22	?	CLI	FIRE	UDF		LOST ALL POWER AT 165 FT-STEEP BANK-CRASHED ON AUTOBAN-HIT BRIDGE
112872 DC8 MOSCOW, USSR	X	76	62	15	CLI	FIRE	UDF		STALL DUE TO FLAP RETRACTION
010274 F28 IZMIR, TURKEY	X	72	65	7	CLI	FIRE	UDF		AT 33 FT BANKED LEFT AND CRASHED-PROBABLY STALL
112074 747 NAIROBI, KENYA	X	157	59	44	CLI	FIRE	PAR		NOSE HIGH STALL-AFT FUSELAGE HIT ELEVATED ROAD-A/C BROKE UP
080775 727 DENVER	X	134	0	15	CLI		YES		WIND SHEAR-STALL
020979 DC9 MIAMI	X	5	0	1	CLI		YES		ENG OUT TRAINING-WING HIT GRD
N= 12									

TABLE 10. - CONTINUED

(c) Approach

(a) Takeoff
(b) Climb
(c) Approach
(d) Landing
(e) Taxi

Date	A/C	Location	Hull Loss	Onboard	Fatal	Serious Injury	Flight Phase	Fire	Impact Survivable	Water Landing	Description
101959	707	OSO, WASHINGTON	X	8	4	0	APP	FIRE	PAR	WAT	ATTEMPTED CRASH LDG IN RIVER-HIT TREES-FWD FUSELAGE DESTROYED
082759	CMT	ASUNCION	X	50	2	?	APP		UDF		INSTRUMENT APPROACH-TOUCHDOWN 5.5 MILES FROM RUNWAY
070363	CVL	CORDOBA, ARGENTINA	X	70	0	?	APP	FIRE	YES		SHORT-HIT TREES, TANKS RUPTURE, FIRE-HIT RAILROAD TRACKS-LOST GEAR
050265	720	CAIRO	X	127	121	6	APP	FIRE	UDF		HIGH RATE OF DESCENT-IMPACTED HILL IN LEFT TURN-SURVIVORS EJECTED
110865	727	CINCINNATI	X	62	58	4	APP	FIRE	PAR		IMPACTED WOODED HILL-A/C BROKE UP
030466	DC8	TOKYO	X	72	64	8	APP	FIRE	UDF		WINDSHEAR-A/C HIT APPROACH LIGHTS AND SEAWALL-SURVIVORS EJECTED
063066	TRI	KUWAIT	X	83	0	0	APP		YES		LANDED IN SANDY SOIL-SEPARATED GEAR-MINOR FUEL SPILL
122466	DC8	MEXICO CITY	X	110	0	6	APP	FIRE	YES		LANDED IN DRY LAKE BED-HIT 3FT HIGH ROAD, SHED N.G.-FUSELAGE BROKE
021566	CVL	NEW DELHI	X	81	2	14	APP	FIRE	YES		A/C HIT CEMENT PILLAR-GEAR FAILED-WING TANKS RUPTURED-FIRE
112067	880	CINCINNATI	X	82	70	12	APP	FIRE	PAR		IMPACTED WOODED HILL-A/C BROKE UP
030567	DC8	MONROVIA	X	90	51	23	APP	FIRE	UDF		HIGH RATE OF DESCENT-LOST ENGINES AND GEAR-HIT SEVERAL HOUSES-FIRE
063067	CVL	HONG KONG	X	80	17	5	APP		YES	WAT	SHORT, IN WATER, NOSE UP-A/C FUSELAGE BROKE-A/C SANK-PAX DROWNED
061368	707	CALCUTTA	X	63	6	2	APP	FIRE	YES		SHORT-HIT TREES AND HOUSE TOPS-LOST GEAR AND 3 ENGINES-FUEL LEAK-FIRE
021668	727	TAIPEI	X	63	21	42	APP	FIRE	UDF		SHORT-HIT TREES, FARM HOUSE, MORE TREES-A/C BROKE UP AND BURNED
080268	DC8	MILAN	X	95	12	?	APP	FIRE	YES		WINDSHEAR-MILD IMPACT ON HILL WITH TREES-A/C INTACT-FUEL SPILL, ENGINE FIRE
010569	727	LONDON GATWICK	X	65	50	14	APP	FIRE	PAR		SHORT-HIT TREES, HOUSE A/C DISINTEGRATED IN SLIDE OUT-FIRE
011369	DC8	LOS ANGELES	X	45	15	17	APP		YES	WAT	IMPACT SANTA MONICA BAY-A/C FUSELAGE BROKE AND SANK-PAX DROWNED
092169	727	MEXICO CITY	X	118	28	78	APP		PAR	WAT	IMPACT SHORT IN SHALLOW LAKE-SLID 900 FT AND HIT 10 FT HIGH RR BED-A/C BROKE UP
091269	BAC	MANILA	X	47	45	2	APP	FIRE	PAR		HIT HILL-SURVIVORS EJECTED
072770	DC8	NAHA, OKINAWA	X	4	4	0	APP		PAR	WAT	IMPACTED WATER-A/C BROKE UP-2 CREW TRAPPED IN COCKPIT DROWNED
033170	CVL	CASABLANCA	X	82	61	21	APP	FIRE	UDF		A/C HIT POWER LINES, IMPACTED ON HIGHWAY-BOUNCED IN BALL OF FLAME-FUSELAGE BROKE
120770	BAC	CONSTANA	X	27	18	?	APP		UDF		SHORT
120872	737	CHICAGO MIDWAY	X	61	43	12	APP	FIRE	PAR		STALLED-IMPACTED HOUSES AND TREES-A/C BROKE UP-FIRE
122972	L10	MIAMI	X	176	99	60	APP	FIRE	PAR	WAT	IMPACTED IN EVERGLADES-A/C DISINTEGRATED-MOST SURVIVORS EJECTED
012172	DC9	ADANA	X	5	1	?	APP	FIRE	YES		IMPACTED ON DOWNWIND LEG AND BURNED
122372	F28	OSLO	X	45	40	?	APP	FIRE	UDF		A/C IMPACTED IN FOREST-DISINTEGRATED AND BURNED
073173	DC9	BOSTON, MASS.	X	89	89	0	APP	FIRE	PAR		A/C HIT SEAWALL AND DISINTEGRATED AND BURNED
112773	DC9	CHATTANOOGA	X	77	0	5	APP	FIRE	YES		HIT APPROACH LIGHTS-LT WING, ENGINE AND GEAR SEPARATED-FUSELAGE BROKE
053173	737	NEW DELHI	X	65	52	?	APP	FIRE	YES		SHORT-HIT BOULDERS-SEP GEAR, RT WING, #2 ENGINE-FUSELAGE BROKE AND BURNED
060973	707	RIO DE JANEIRO	X	4	2	0	APP		PAR	WAT	INADVERTENT SPOILERS-A/C HIT APPROACH LIGHTS-IMPACTED WATER
011374	707	PAGO PAGO, AM. SAMOA	X	101	97	5	APP	FIRE	YES		A/C HIT TREES, LAVA WALL, AND DITCH-TANKS RUPTURED-FIRE
091174	DC9	CHARLOTTE, N.C.	X	82	71	10	APP	FIRE	PAR		A/C LANDED IN FIELD, HIT TREES-SEPARATED GEAR AND WINGS-IMPACTED GULLEY-FIRE
010174	F28	TURIN, ITALY	X	42	38	4	APP	FIRE	UDF		IMPACT SHORT-FUSELAGE BROKE AND BURNED
062475	727	JFK	X	124	112	12	APP	FIRE	PAR		WINDSHEAR-HIT APPROACH LIGHTS-A/C BROKE UP
111275	727	RALEIGH, N.C.		139	0	1	APP		YES		WINDSHEAR-HARD IMPACT
111575	F28	NR. BUENOS AIRES	X	66	0	0	APP		YES		A/C HIT TREE-LOST GEAR AND LT WING TIP ON GRD IMPACT-HIT LARGE TREE
042276	720	BARRANQUILLA, COL.	X	4	0	1	APP	FIRE	YES		A/C HIT TREES-LOST BOTH WINGS-FUSELAGE BROKE
030477	DC8	NIAMEY, NIGER	X	4	2	2	APP	FIRE	YES		SHORT-HIT DITCHES-A/C BROKE UP IN SLIDE
040477	DC9	NEW HOPE, GA.	X	85	62	22	APP	FIRE	PAR		LANDED ON HIGHWAY-HIT TREES, POLES, CARS, BUILDINGS, FUSELAGE BROKE FIRE
092777	DC8	KUALA LUMPUR	X	79	34	?	APP	FIRE	UDF		CRASHED ON RUBBER PLANTATION
112177	BAC	BARILOCHE, ARG.	X	79	45	34	APP		UDF		IMPACTED ROCKY AREA
121877	CVL	MADEIRA	X	57	36	13	APP		YES	WAT	A/C TOUCHED DOWN IN WATER-FLOATED 5 MINUTES-PAX DROWNED
050878	727	PENSACOLA	X	58	3	11	APP		YES	WAT	IMPACTED WATER IN APPROACH ATTITUDE-PAX DROWNED
111578	DC8	COLUMBO, SRI LANKA	X	259	195	?	APP	FIRE	UDF		CRASHED IN THUNDERSTORM-HIT COCONUT TREES-MOST SURVIVORS FROM AFT SECTION
122978	DC8	PORTLAND, OREGON	X	186	10	23	APP		PAR		RAN OUT OF FUEL-HIT POLES, BANKS, HOUSES, TREES-FWD FUSELAGE CRUSHED
021979	707	ST. LUCIA		170	0	0	APP		YES		HARD IMPACT-FUSELAGE FLOOR DISTORTED
031479	727	DOHA, QATAR	X	64	45	15	APP	FIRE	PAR		WINDSHEAR-HARD TAIL DOWN IMPACT-HIT BLDG

N= 46

ORIGINAL PAGE IS OF POOR QUALITY

TABLE 10. - CONTINUED

(a) Takeoff
(b) Climb
(c) Approach
(d) Landing
(e) Taxi

(d) Landing

			HULL LOSS	ONBOARD	FATAL	SERIOUS INJURY	FLIGHT PHASE	FIRE	IMPACT SURVIVABLE	WATER LANDING	DESCRIPTION
022060	CMT	BUENOS AIRES	X	6	0	0	LDG	FIRE	YES		HARD IMPACT-GEAR FAILED LOST POD TANKS-FIRE-TRAINING
071161	DC8	DENVER	X	122	17	0	LDG	FIRE	YES		HYDRAULICS FAILED-A/C VEERED OFF RUNWAY-HIT TRUCK-LOST ALL GEAR,ENG. 1,2,4-BURNED
061561	707	LISBON		103	0	2	LDG	FIRE	YES		HARD LDG-COLLAPSE NOSE GEAR
092761	720	BOSTON		71	0	2	LDG		YES	WAT	LONG,HARD LANDING-GEAR COLLAPSE F[illegible]CTION FIRE-TANKS LEAKED
092761	CVL	BRASSILA	X	?	?	?	LDG	FIRE	UDF		SHORT, HARD LANDING-GEAR COLLAPSE FRICTION FIRE TANKS LEAKED
031864	BAC	WISLEY, ENG.		5	0	1	LDG		YES		HARD LANDING-SEPARATED ONE ENGINE, NOSE & RMG
040764	707	JFK	X	145	0	7	LDG		YES	WAT	OVERRUN-ENTERED THURSTON BASIN
032264	CMT	SINGAPORE	X	86	0	0	LDG	FIRE	YES		LMG FAILED-A/C STOPPED ON REMAINING GEAR AND LEFT WING TIP-FIRE
070165	707	KANSAS CITY	X	66	0	2	LDG		YES		GRD LOOP ON OVERRUN-HIT BLG, LEVEE
111165	727	SALT LAKE CITY	X	91	43	35	LDG	FIRE	YES		HIGH RATE OF DESCENT-GEAR FAILURE-FUEL LINE FIRE
022765	880	IKI IS., JAPAN	X	6	0	2	LDG	FIRE	YES		SHORT-GEAR SHEARED ON RUNWAY LIP-RUPT TANK-FIRE
092967	CMT	ROME	X	66	0	0	LDG		YES		HARD LDG-VEERED OFF RUNWAY-HIT CONCRETE BOX-FUEL SPILL
032868	DC8	ATLANTIC CITY	X	4	0	2	LDG	FIRE	YES		2 ENG OUT TRAINING-VEERED OFF RUNWAY HIT DITCH-LOST GEAR-ENG FIRE
060368	727	JFK		102	0	4	LDG		YES		HIT ILS TOWER-LOST GEAR
020768	707	VANCOUVER, B.C.	X	61	1	0	LDG		PAR		VEERED OFF RUNWAY-HIT BLG
101669	DC8	STOCKTON, CA.	X	5	0	0	LDG	FIRE	YES		OVERRUN-HIT DITCH-LOST GEAR, ENGINE-FUEL SPILL
021170	707	STOCKTON,CA		6	0	1	LDG		YES		VEERED OFF RUNWAY-HIT DITCH-LOST NOSEGEAR-FRACTURED WING
090870	DC9	LOUISVILLE		94	0	0	LDG	FIRE	YES		SHORT ON 5° SLOPE-BROKE FUSELAGE-BOUNCED ONTO RUNWAY
122870	727	ST. THOMAS	X	55	2	11	LDG	FIRE	YES		HARD IMPACT-BOUNCED-OVERRUN-HIT TRUCK-SLIDE UP HILL-A/C BROKE UP
080870	990	ACAPULCO	X	8	0	8	LDG	FIRE	YES		HARD IMPACT-FAILED WINGS
050270	DC9	ST. CROIX, V.I.	X	63	25	25	LDG		PAR	WAT	IMPACT WATER-PAX DROWNED
070570	DC8	TORONTO	X	108	108	0	LDG	FIRE	YES		HARD-TAIL FIRST-#4 ENG HIT RUNWAY, SEPARATED-FIRE-EXPLOSION ON GO AROUND
091570	DC8	JFK	X	156	0	?	LDG	FIRE	YES		HARD LDG.
121571	707	URUMCHI, CHINA	X	3	0	0	LDG		YES		HARD LDG.
051872	DC9	FT. LAUDERDALE	X	10	0	3	LDG	FIRE	YES		HARD LDG.-GEAR SEP. & TANK RUPT.
092472	DC8	BOMBAY	X	120	0	0	LDG	FIRE	YES		RUNWAY TOO SHORT-OVERRUN HIT DITCH
121572	747	MIAMI	X	160	0	0	LDG		YES		OVERRUN-HIT CONCRETE BLG. FOUNDATION
122872	F28	BOLBAO SPAIN	X	4	0	4	LDG		YES		OVERRUN-CROSSED GULLY AND STREAM
112773	DC9	AKRON, OHIO	X	26	0	16	LDG		YES		OVERRUN-FELL INTO 50 FT. DEEP RAVINE
012273	707	KHANO, NIGERIA	X	202	172	?	LDG	FIRE	YES		SHORT-HARD-LOST RMG-LEFT WING SEPARATED-FIRE AT ROOT-FIRE DEATHS
102873	737	GREENSBORO		96	0	0	LDG	FIRE	YES		OVERRUN TO SMALL HILL
061673	707	BUENOS AIRES		86	0	0	LDG	FIRE	YES		HARD LDG.-WING HIT GRD. & SEPARATED-FIRE
062373	DC8	JFK		128	0	8	LDG	FIRE	YES		INADVERTANT SPOILER DEPLOYMENT-HARD LANDING
121773	DC1	BOSTON	X	151	0	3	LDG	FIRE	YES		A/C HIT APPROACH LIGHTS-LDG. & GEARS
121973	707	NEW DELHI	X	109	0	3	LDG	FIRE	YES		A/C HIT MIDDLE MARKER BLG.
122373	CVL	MANAUS, BRAZIL	.	57	0	1	LDG		YES		OVERRUN-WENT DOWN A SLOPE TO 50 FT. BELOW RUNWAY
011674	707	LOS ANGELES	X	63	0	3	LDG	FIRE	YES		HARD-NOSEDOWN IMPACT-NO FLARE
091174	727	PORTO ALEGRE,BRAZIL		74	0	0	LDG		YES		LONG AND FAST-WENT THROUGH 2 BRICK WALLS
033175	737	CASPER, WYO.	X	99	0	1	LDG		YES		OVERRUN-HIT ILS-DITCH
092475	F28	PALEMBANG	X	62	25	7	LDG	FIRE	UDF		OVERRUN-HIT TREES
010276	DC1	ISTANBUL	X	373	0	1	LDG	FIRE	YES		SHORT-LOST GEAR,ENGS.-LEFT WING SEP.
040576	727	KETCHIKAN	X	57	1	32	LDG	FIRE	PAR		OVERRUN-FLEW OVER GULLY-LANDED IN RAVINE-WING FIRE-FUEL LEAK
042776	727	ST. THOMAS, V.I.	X	88	37	19	LDG	FIRE	PAR		OVERRUN-WENT DOWN SLOPE, CROSSED ROAD-HIT GAS STATION-FUSELAGE BROKE-FIRE
062376	DC9	PHILADELPHIA	X	105	0	36	LDG		YES		WHEELS UP-TAIL FIRST-SLID OFF RUNWAY
111977	727	MADEIRA	X	164	128	36	LDG	FIRE	PAR	WAT	OVERRUN-SLID DOWN 75° EMBANKMENT-HIT BRIDGE-FUEL SPILL-SURVIVORS EJECTED
111777	747	JFK		3	0	0	LDG		YES		VEERED OFF RUNWAY

ORIGINAL PAGE IS
OF POOR QUALITY

TABLE 10. - CONCLUDED

(a) Takeoff
(b) Climb
(c) Approach
(d) Landing
(e) Taxi

(d) Landing (Concluded)

			HULL LOSS	ONBOARD	FATAL	SERIOUS INJURY	FLIGHT PHASE	FIRE	IMPACT SURVIVABLE	WATER LANDING	DESCRIPTION
021178	737	CRANBROOK, B.C.	X	49	42	5	LDG	FIRE	PAR		ABORTED LDG-ATTEMPTED GO ROUND-A/C HIT LT. WING & NOSED DOWN
030378	DC8	SANTIAGO DE COMPO.	X	222	0	52	LDG		YES		OVERRUN WENT DOWN 65' EMBANKMENT
040278	737	SAO PAULO	X	42	0	0	LDG	FIRE	YES		WHEELS UP-DID NOT SHUT OFF FUEL VALVE
040478	737	CHARLROI, BELGIUM	X	3	0	0	LDG	FIRE	YES		OVERRUN-HIT ILS TOWER-TRAINING
070978	BAC	ROCHESTER		77	0	1	LDG		YES		OVERRUN-HIT DITCH
122378	DC9	PALERMO, ITALY	X	129	108	?	LDG		UOF	WAT	IMPACTED LEVEL-BROKE UP AND SANK-PAX DROWNED
032578	720	LONDON		82	0	?	LDG		YES		HIT HARD AND BOUNCED-NOSE GEAR COLLAPSED
042679	737	MADRAS	X	67	0	8	LDG	FIRE	YES		OVERRUN-ROUGH TERRAIN-SEP ENG. & NG & RMLG. LMLG COLLAPSED-MINOR FIRE
100779	DC8	ATHENS	X	154	14	0	LDG	FIRE	YES		OVERRUN-CRACK IN LEFT WING-FIRE
103179	DC1	MEXICO CITY	X	87	70	17	LDG	FIRE	UOF		TOUCHDOWN-HIT VEH., SEP. MLG-AIRBORNE-HIT WING LOW-HIT BLG.
N=	57										

(e) Taxi

			HULL LOSS	ONBOARD	FATAL	SERIOUS INJURY	FLIGHT PHASE	FIRE	IMPACT SURVIVABLE	WATER LANDING	DESCRIPTION
031574	CVL	TEHRAN, IRAN	X	96	15	?	TAX	FIRE	YES		GEAR COLLAPSED-WING HIT GRD-FIRE
121675	747	ANCHORAGE		121	0	2	TAX		YES		SLIDE BACKWARDS OFF RUNWAY-HIT BANK
032777	747	TENERIFE	X	396	334	62	TAX	FIRE	PAR		COLLISION WITH KLM 747-WING RUPTURE-FUSELAGE CRUSHED-FIRE
N=	3										

TABLE 11. -STRUCTURAL DAMAGE SEVERITY

DAMAGE CATEGORY	
1	MINOR IMPACT DAMAGE - INCLUDES ENGINE/ PYLON DAMAGE OR SEPARATION, MINOR LOWER FUSELAGE DAMAGE, AND MINOR FUEL SPILLAGE.
2	MODERATE IMPACT DAMAGE - INCLUDE HIGHER DEGREES OF DAMAGE OF TYPE 1 AND INCLUDES GEAR SEPARATION OR COLLAPSE.
3	SEVERE IMPACT DAMAGE - INCLUDES SEVERE LOWER FUSELAGE CRUSH AND/OR CLASS 1 OR CLASS 2 FUSELAGE BREAKS, MAY HAVE GEAR COLLAPSE, BUT NO TANK RUPTURE.
4	SEVERE IMPACT DAMAGE BUT NO FUSELAGE BREAK - INCLUDES MAJOR FUEL SPILLAGE DUE TO WING LOWER SURFACE TEAR AND WING BOX DAMAGE.
5	EXTREME IMPACT DAMAGE - INCLUDES CLASS 1 OR CLASS 2 FUSELAGE BREAKS WITH WING SEPARATION OR BREAKS, MAY HAVE GEAR AND/OR ENGINE SEPARATION.
6	AIRCRAFT DESTRUCTION - INCLUDES CLASS 3 FUSELAGE BREAKS OR DESTRUCTION WITH TANK RUPTURE, GEAR AND/OR ENGINE SEPARATION.

FUSELAGE BREAKS: CLASS 1 - SECTIONS BREAK REMAIN TOGETHER
CLASS 2 - SECTIONS BREAK AND OPEN
CLASS 3 - SECTIONS BREAK AND MOVE OFF

TABLE 12. - NUMBER OF FATALITIES AS A FUNCTION OF DAMAGE SEVERITY

CATEGORY	ACCIDENTS	HULL LOSS	FIRE	OCCUPANTS	TOTAL FATALITIES		FIRE		TRAUMA		DROWNING		UNKNOWN	
					NO.	%	NO.	%	NO.	%	NO.	%	NO.	%
1	5	3	4	616	53	8.6	53	8.6	0	0	0	0	0	0
2	24	12	6	1684	1	.06	0	0	1	.06	0	0	0	0
3	22	20	9	2024	225	11.11	55	2.72	5	0.25	165	8.15	0	0
4	40	36	35	3425	875	25.54	722	21.08	5	.15	18	.53	130	3.80
5	35	35	28	2618	934	35.68	335	12.80	210	8.02	32	1.22	357	15.93
6	20	20	18	1990	1547	77.74	189	9.50	190	9.54	3	0.15	1165	58.94
UNKNOWN*	7	7	3	311	156	50.16	2	.64	65	20.90	0	0	89	28.6
TOTAL	153	133	103	12668	3791	29.93	1356	10.70	476	3.76	218	1.72	1741	13.74

* INSUFFICIENT INFORMATION FOR CATEGORY ASSIGNMENT

TABLE 13. - FAILURE MECHANISMS

● FUSELAGE	● WING
CRUSH (AXIAL & VERT)	BREAKS
BENDING BREAKS	WING BOX DESTRUCTION
LOCAL DEFORMATIONS	DISTORTION
TANGENTIAL DAMAGE	
	● ENGINES/PYLONS
● GEAR	SEPARATION
SEPARATION	
COLLAPSE	● SEATS
	SEPARATION
● HATCH/DOOR/FLOOR	DISTORTION
DISTORTION	RUPTURE
DESTRUCTION	
SEPARATION	● INTERIORS
	GALLEY/DIVIDERS SEPARATION - SPILLAGE
● BELTS/HARNESS	COMPARTMENT SEPARATION - SPILLAGE
RUPTURE	PANEL DISLODGEMENT
EJECTION	

ORIGINAL PAGE IS
OF POOR QUALITY

TABLE 14. - INJURY TYPES

● TRAUMA		● FIRE/ SMOKE/ NOXIOUS GASES
HEAD	FRACTURE, CONCUSSION	BURNS
NECK	FRACTURE	VASCULAR DAMAGE
CHEST	CRUSH, RIB FRACTURE	ASPHYXIATION
SPINE	FRACTURE	
LIMBS	FRACTURE, AMPUTATION	
● DROWNING		

TABLE 15. - STRUCTURAL SYSTEMS (REF. 19)

(a)

SYSTEM	CRASH FUNCTION	CRASH DYNAMICS	INTERACTION	DIRECT RESULT
Landing Gear	Energy absorption Maintain grd. clearance Separate with no damage to airframe	Stroke/ gear deformation	Load airframe	Energy absorption by gear
Nose		Collapse aft/ side and/ or sep.	Forward fuselage grd. contact	Energy absorption by grd. friction Energy absorption by lwr. fuse. def.
			Penetrate lower fuselage	Gear damage Floor deformation Fire entry to cabin Fuselage break
Main/Body		Collapse or separation aft/ side	Center fuselage	Water/ fuel/ fire entry to lwr. fuse.
			Lwr. fuse. penetration	Energy absorption by pylon def.
			Wing pod grd. contact	Grd. impact loads to wing
			Wing grd. impact	
			Wing box tear Slewing of A/ C	Fuel spill/ fire Fuselage break
			Lwr. fuse. penetration Aft structure contact	Body fuel line break/ fire Empennage damage
Wing Pylon/ Engine	React obstructions	Deformation	Load wing structure	Pylon/ engine damage Engery absorption Load wing structure Grd. friction
	Energy absorption Separate with no damage to airframe	Collapse/ separation	Fuel/ electric/ hydraulic line rupture	Pylon/ engine damage
			Wing box web tear Wing lower surface penetration Wing ground contact	Fluid spill/ arcing/ fire Wing box break Energy absorption
	Provide grd. reaction			

TABLE 15. - CONTINUED

(b)

SYSTEM	CRASH FUNCTION	CRASH DYNAMICS	INTERACTION	DIRECT RESULT
Aft Pylon/Engine	Separate with no damage to airframe	Deformation/Separation	Fuel/electric line rupture	Pylon/engine damage Fuel spill/arcing/fire Fuselage fire damage
Wing Structure	Support main gear Support engine/pylon	Deformation	Load fuse. structure	Energy absorption Fuel leak Wing damage
	Contain fuel Reacts obstructions	Separation	A/C dynamics/flotation loss Hinder egress	Fuel spill/fire Wing damage
	Prevent A/C roll Energy absorption	Wing box break	A/C dynamics/flotation loss	Fuel spill/fire Wing damage
	Egress route Provide flotation	Lower surface tear	Fuel spill/fire Wing damage	
Fuselage	React obstructions	Lower fuselage crush	Floor displacement Cargo displacement Upper fuselage distortion Body fuel/elec. line rupture	Energy absorption by deformation Energy absorption by grd. friction Fuel/fire/smoke/water/mud entry Flotation loss Fuselage damage Fuel spill/arcing Floor elevation
	Protective shell Energy absorption	Upper fuselage distortion	Seats Door/hatches Cabin interior Floor structure	Survivable vol. loss Egress blockage Seat lateral displace.
	Flotation Egress	Fuselage break	Seats/track/floor beam Cabin interior items Doors/hatches Body fuel lines	Energy absorption by deformation Survivable vol. loss Occupant ejection/egress route Loose cabin interior items Floor/seat track rupture High floor accel.

TABLE 15. - CONCLUDED

(c)

SYSTEM	CRASH FUNCTION	CRASH DYNAMICS	INTERACTION	DIRECT RESULT
	Support floor beams Support cabin interior items	Fuselage disintegration	Floor struc. displace. Seats Cabin interior items	Fuel/ fire entry Seat separation/ ejection Cabin debris Flotation loss Energy absorption Fuselage damage
Fuel Task Storage System	Constraint/ baggage-cargo Retain structural integrity Limit fuel spillage	Engine line rupture Body line rupture	Pylon/ engine Fuselage	Fuel spill
Floor structure	Restraint seats/ track Energy absorption Provide egress Cabin interior items Retain structural integrity	Deformation Rupture	Seat track/ seats Cabin interior items Doors/ hatches Seat tracks/ seats Cabin interior items	Energy absorption Egress blockage
Seats/ Restraints System	Occupant containment/ protection	Seat track deform. / rupt.	Floor beams	Seat elevation/ separation
	Energy adsorption	Seat deformation	Seat tracks	Energy absorption Load limiting
	Remain attached to floor Release as required (belts/ harness)	Seat rupture Belt/ harness rupture	Seats structure Bulkhead structure	Occupant release/ injury Occupant ejection/ injury Energy absorption
Cabin Interior Sys.	Contents containment Remain attached to structure	Overhead compart. spillage Overhead compart. sep. Ceiling panel/ sidewall sep. Galley/ closet/ divider sep. Galley/ closet spillage	Upper fuselage Floor beams	Cabin debris Egress blockage Occupant injury
Entry and Escape Doors	Operate as required	Blockage by debris Jammed by floor Jammed by fuselage distort. Inadvertent opening	Cabin interior systems Floor structure Upper fuselage	Egress blockage Fuel/ fire/ smoke entry

ORIGINAL PAGE IS OF POOR QUALITY

ORIGINAL PAGE IS
OF POOR QUALITY

TABLE 16. - STRUCTURAL COMPONENT PARTICIPATION (REF. 19)

NUMBER OF ACCIDENTS - 153 TOTAL

	HULL LOSS	FIRE	GEAR SEP.	ENGINE SEP.	FUSELAGE CRUSH BREAK	TANK RUPTURE	CABIN INTERIOR	SEATS	DOORS	FLOORS	BODY FUEL LINES	WATER
HULL	133	95	80	70	90	100	37	36	40	32	7	15
FIRE	95	103	64	59	70	85	25	27	28	21	5	4
GEAR	80	64	95	57	62	71	33	26	38	33	5	8
ENGINE	70	59	57	80	61	61	30	28	28	26	4	10
FUSELAGE	90	70	62	61	100	73	34	38	41	38	5	14
TANK	100	85	71	61	73	107	33	32	31	25	6	10
CABIN	37	25	33	30	34	33	45	26	24	22	2	7
SEATS	36	27	26	28	38	32	26	41	23	24	3	5
DOORS	40	28	38	28	41	31	24	23	47	30	3	5
FLOORS	32	21	33	26	38	25	22	24	30	42	3	7
LINES	7	5	5	4	5	6	2	3	3	3	7	2
WATER	15	4	8	10	14	10	7	5	5	7	2	16

TABLE 17. - COMPONENT PARTICIPATION AND ACCIDENT SEVERITY AS A FUNCTION OF ACCIDENT SCENARIO

	OCCUPANTS	FATALITIES	% OCCUPANTS	FIRE FATALITIES	% OCCUPANTS	TRAUMA	% OCCUPANTS	DROWN	% OCCUPANTS	UNKNOWN	% OCCUPANTS
AIR-TO-SURFACE	4447	139[illegible]	31.3	45[illegible]	10.2	133	3.0	202	4.5	604	13.6
UNKNOWN	121	83	68.6	0	0	45	37.2	0	0	38	31.4
IMPACT OTHER THAN GEAR	1141	677	59.3	150	13.1	76	6.7	0	0	451	39.5
IMPACT ON GEAR	2749	425	15.5	302	11.0	8	3	0	0	115	4.2
IMPACT ON WATER	436	206	47.2	0	0	4	9	202	46.3	0	0
SURFACE-TO-SURFACE	4974	989	19.9	412	8.3	214	4.3	16	3	347	7
HARD GROUND	182	15	8.2	15	8.2	0	0	0	0	0	0
SOFT EARTH	1127	219	19.4	37	3.3	41	3.6	15	1.3	126	11.2
LOW OBSTRUCTION	2702	676	25.0	315	11.7	165	6.1	0	0	196	7.3
HIGH OBSTRUCTION	681	78	11.5	45	6.6	8	1.2	0	0	25	3.7
SLIDE INTO WATER	282	1	4	0	0	0	0	1	4	0	0
FLIGHT INTO OBSTRUCTIONS	2278	1134	49.8	462	20.3	10[illegible]	4.4	0	0	572	25.1
WING LOW	442	332	75.1	32	7.2	18	4.1	0	0	282	63.8
COLUMN	1135	249	21.9	125	11.0	63	5.6	0	0	61	5.4
SOLID WALL	285	264	92.6	35	12.3	0	0	0	0	229	80.4
HIGH OBSTRUCTION	416	289	69.5	270	64.9	19	4.6	0	0	0	0
UNCLASSIFIED	969	277	28.6	30	3.1	29	3.0	0	0	218	22.5
TOTALS	12668	3791	29.9	1356	10.7	476	3.8	218	1.7	1741	13.7

	NUMBER OF ACCIDENTS	HULL LOSS	FIRE	FUSELAGE	TANK RUPTURE	ENGINE SEPARATION	CABIN INTEGRITY	SEATS	GEAR SEPARATION	DOORS	FLOORS	LINES	WATER
AIR-TO-SURFACE	53	44	33	40	35	25	17	18	32	21	18	4	9
UNKNOWN	2	2	1	1	1	0	0	0	0	0	0	0	0
IMPACT OTHER THAN GEAR	13	13	12	11	12	9	1	6	5	3	1	1	1
IMPACT ON GEAR	31	22	20	23	18	14	12	10	23	14	12	2	1
IMPACT ON WATER	7	7	0	5	4	2	4	2	4	4	5	1	7
SURFACE-TO-SURFACE	61	52	39	34	39	3[illegible]	21	15	45	15	13	3	4
HARD GROUND	2	2	2	0	2	0	0	0	2	0	0	0	0
SOFT EARTH	13	10	10	7	10	9	7	2	13	3	2	0	1
LOW OBSTRUCTION	3[illegible]	30	22	19	21	16	10	8	26	9	9	2	1
HIGH OBSTRUCTION	9	8	5	6	6	6	2	2	4	2	2	1	0
SLIDE INTO WATER	2	2	0	2	0	2	2	1	0	1	0	0	2
FLIGHT INTO OBSTRUCTIONS	30	28	24	23	28	19	7	10	18	11	11	0	3
WING LOW	8	7	7	7	7	5	1	2	3	3	3	0	1
COLUMN	16	15	11	11	15	9	5	5	11	6	6	0	2
SOLID WALL	3	3	3	3	3	2	0	2	1	0	1	0	0
HIGH OBSTRUCTION	3	3	3	2	3	3	1	1	3	2	1	0	0
UNCLASSIFIED	9	9	7	3	5	3	0	0	0	0	0	0	0
TOTALS	153	133	103	100	107	80	45	41	95	47	42	7	16

	DAMAGE CATEGORY 1	2	3	4	5	6	UNKNOWN
AIR-TO-SURFACE	2	7	14	10	11	8	1
UNKNOWN	0	0	0	0	1	0	1
IMPACT OTHER THAN GEAR	0	1	3	0	3	6	0
IMPACT ON GEAR	2	6	10	7	5	1	0
IMPACT ON WATER	0	0	1	3	2	1	0
SURFACE-TO-SURFACE	1	14	17	1[illegible]	13	4	2
HARD GROUND	0	0	2	0	0	0	0
SOFT EARTH	0	4	4	1	2	2	0
LOW OBSTRUCTION	1	7	7	7	10	1	2
HIGH OBSTRUCTION	0	3	4	0	1	1	0
SLIDE INTO WATER	0	0	0	2	0	0	0
FLIGHT INTO OBSTRUCTIONS	0	2	9	2	9	7	1
WING LOW	0	1	1	0	3	3	0
COLUMN	0	1	6	2	5	2	0
SOLID WALL	0	0	0	0	0	2	1
HIGH OBSTRUCTION	0	0	2	0	1	0	0
UNCLASSIFIED	2	1	0	0	2	[illegible]	3
TOTALS	5	24	40	22	35	20	7

ORIGINAL PAGE IS
OF POOR QUALITY

TABLE 18. - AREAS FOR R&D ON CURRENT METAL AIRCRAFT

COMPONENT	CRASH FUNCTION	POTENTIAL FOR IMPROVED PERFORMANCE	AREAS FOR R&D	COMMENTS
Landing Gear	Grd. Clearance	B	Terrain Tolerance	Reduce fuel spills due to grd. drag, lower surface tear; engine/pylon separation; lower fuselage crush; and fire hazard
	Clean Separation	C	Controlled Rupture of Support Structure	Reduce fuel spills due to tank tear and fire hazard
Pylon/Engine	Clean Separation	C	Controlled Rupture of Support Structure	Reduce fuel spill from tank tear and fire hazard
			Fuel, Hydraulic, Electric Line Separation	Reduce fire hazard
Wing Tankage	Contain Fuel	A	Improved Resistance to Rupture and Lower Surface Tear	Reduce fire hazard
Fuselage	Retain Integrity	B	Resistance to Breaks	Better occupant protection
	Prevent Fire Entry	B	Prevention of Holes	
			Heat Rejection	
	Flotation	B	Resistance to Breaks	
Lower Fuselage	Energy Absorption	C	Increase Energy Absorption	Lower loads on occupants and cabin interior equipment
	Prevent Water Entry	B	Increased Plate Strength	Improve flotation and reduce floor displacement

TABLE 18. - CONCLUDED

SYSTEM	CRASH FUNCTION	POTENTIAL FOR IMPROVED PERFORMANCE	AREAS FOR R&D	COMMENTS
Upper Fuselage	Protective Shell	C	Energy Absorption and Integrity	
	Energy Absorption	C		
Fuel Distribution System	Limit Fuel Spillage	B	Fuel Line Separation	Reduce fire hazard
Floor Structure	Energy Absorption	B	Energy Absorption	Reduce occupant loads
	Retain Seats and interior Equipment	C	Controlled Deformation	Improve seat retention
	Provide Egress	C		Reduce door blockage
Seats Restraint System	Occupant Constraint	C	Occupant Dynamic Response	Reduce occupant injury due to surface contact and to restraint loads
	Energy Absorption	C	Improved Energy Absorption	Reduce occupant loads
	Remain Attached to Floor Track	B	Seat/Floor Dynamic Response to Crash Accelerated Loads	Prevent ejection and contact with interior Acceleration environment requirement definition
	Release as Required	C	Ease of Release	
Cabin Interior	Contents Containment	B	Dynamic Response	Reduce debris and occupant injury
	Structural Integrity	B	Structural Attachments	Reduce egress blockage
Entry and Escape Doors	Operate as Required	B	Effects of Fuselage Distortion on Operation	Reduce egress blockage

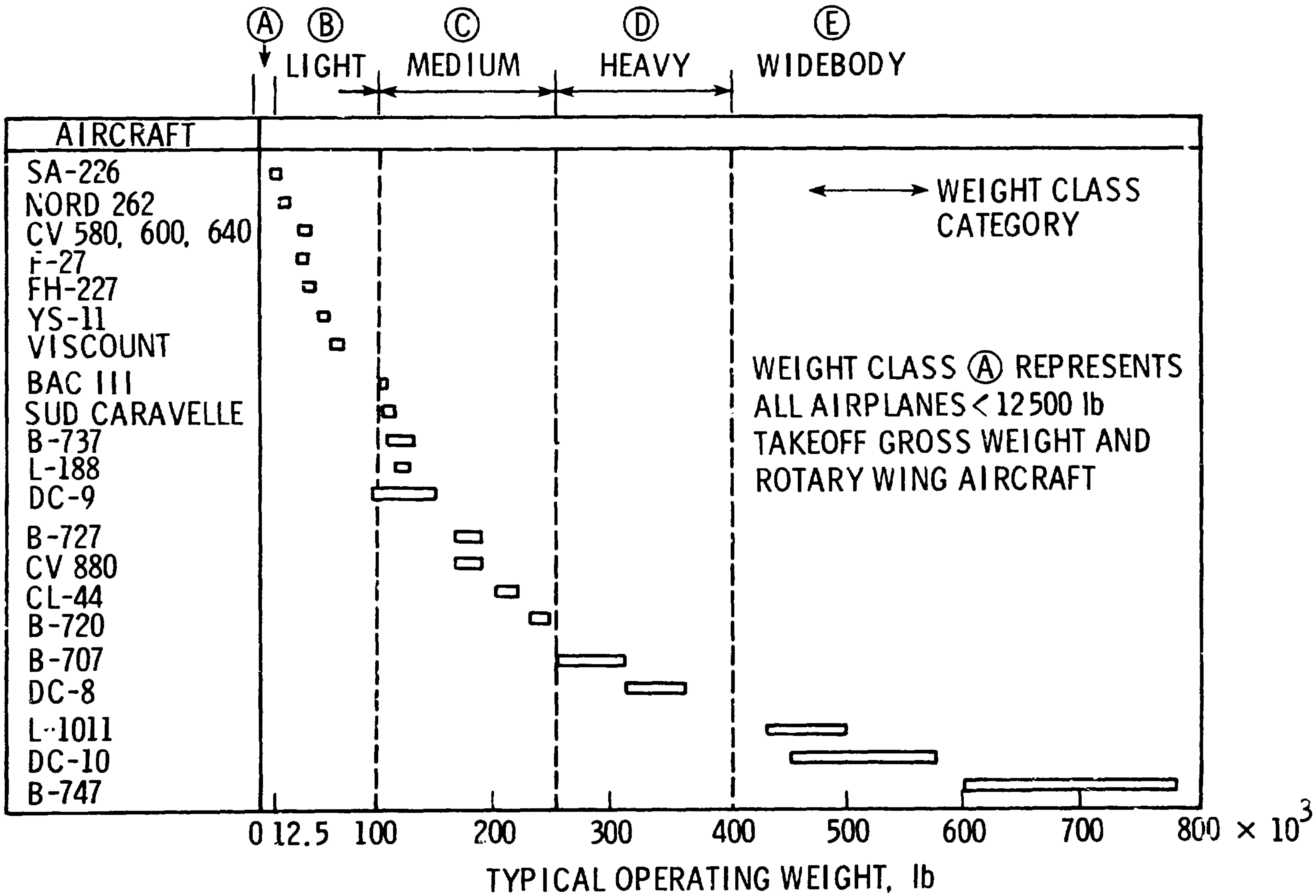


FIGURE 1(A). - TRANSPORT AIRPLANE VS TAKEOFF GROSS WEIGHT

ORIGINAL PAGE IS
OF POOR QUALITY

WEIGHT CLASS		SERVICE-YRS*		NUMBER OF AIRCRAFT CURRENTLY IN SERVICE	
D	707	7508		438	
	DC-8	6009		301	
		13517	26.9 %	739	13.4 %
E	747	2382		517	
	DC-10	1561		342	
	L-1011	892		215	
		4835	9.6 %	1074	19.5 %
C	720	1754		74	
	880/990	438		13	
	727	13234		1636	
		15 426	30.7 %	1723	31.3 %
C	DC-9	8192		941	
	737	4247		779	
	CARAVELLE	1962		93	
	BAC III	2021		156	
		16 422	32.7 %	1969	35.8 %
		TOTAL 50 200		TOTAL 5505	

*NUMBER OF AIRCRAFT × YEARS IN SERVICE

FIGURE 1(B). - NUMBER AND SERVICE - YEARS* OF JET TRANSPORT AIRCRAFT CURRENTLY IN SERVICE

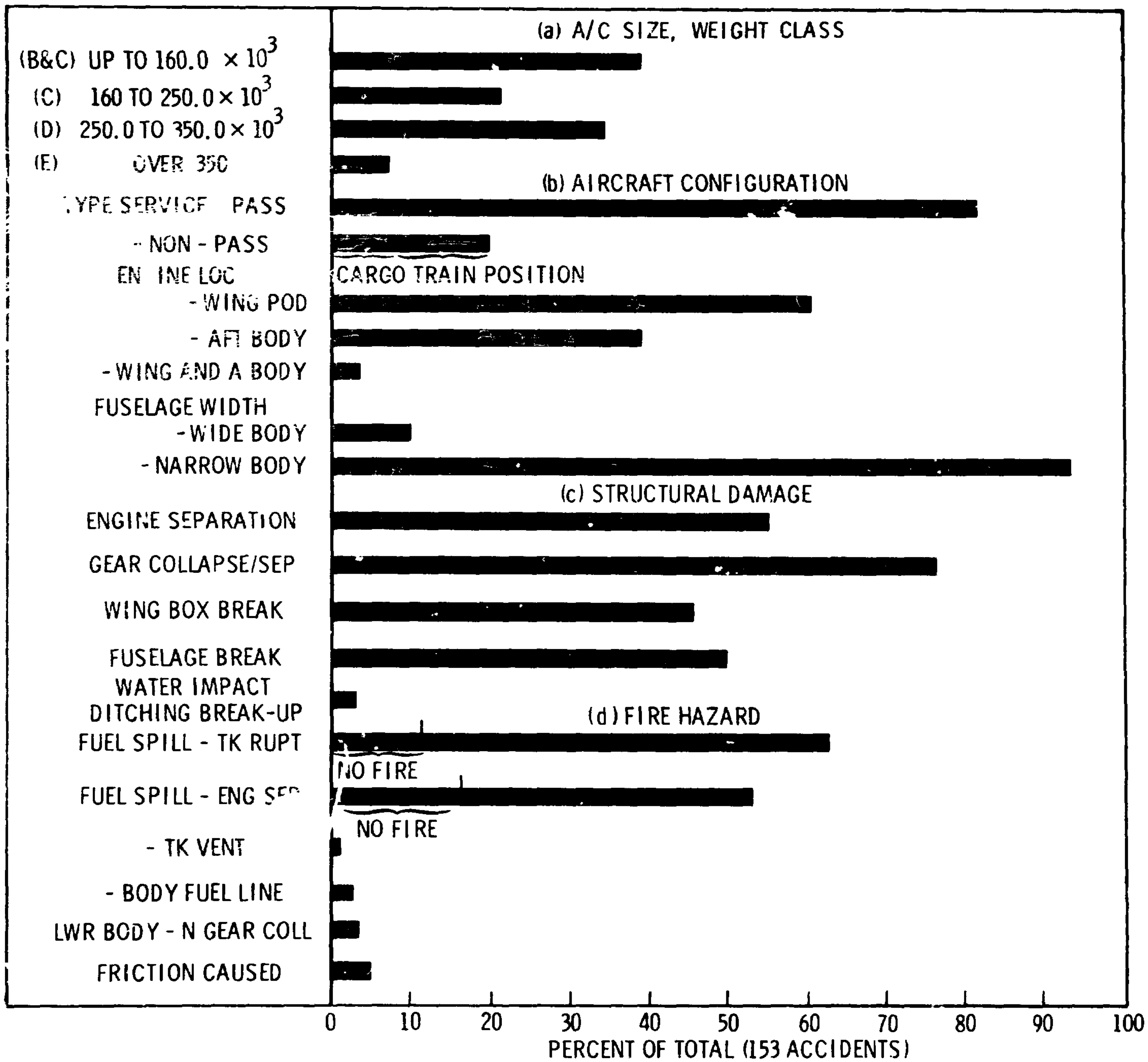


FIGURE 2. - AIRCRAFT SIZE AND CONFIGURATION

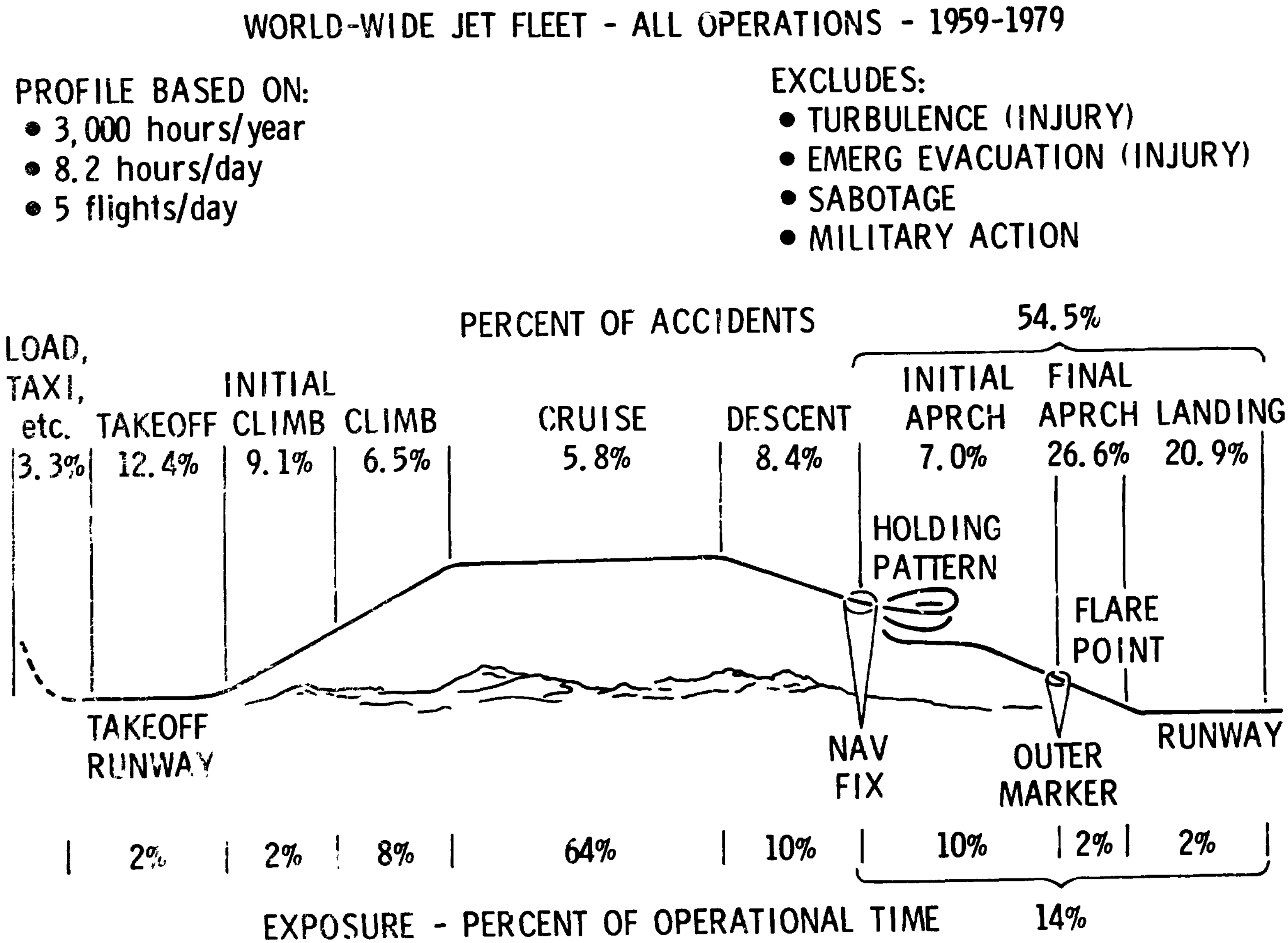


FIGURE 3. - ACCIDENTS AS A FUNCTION OF OPERATIONAL REGIME

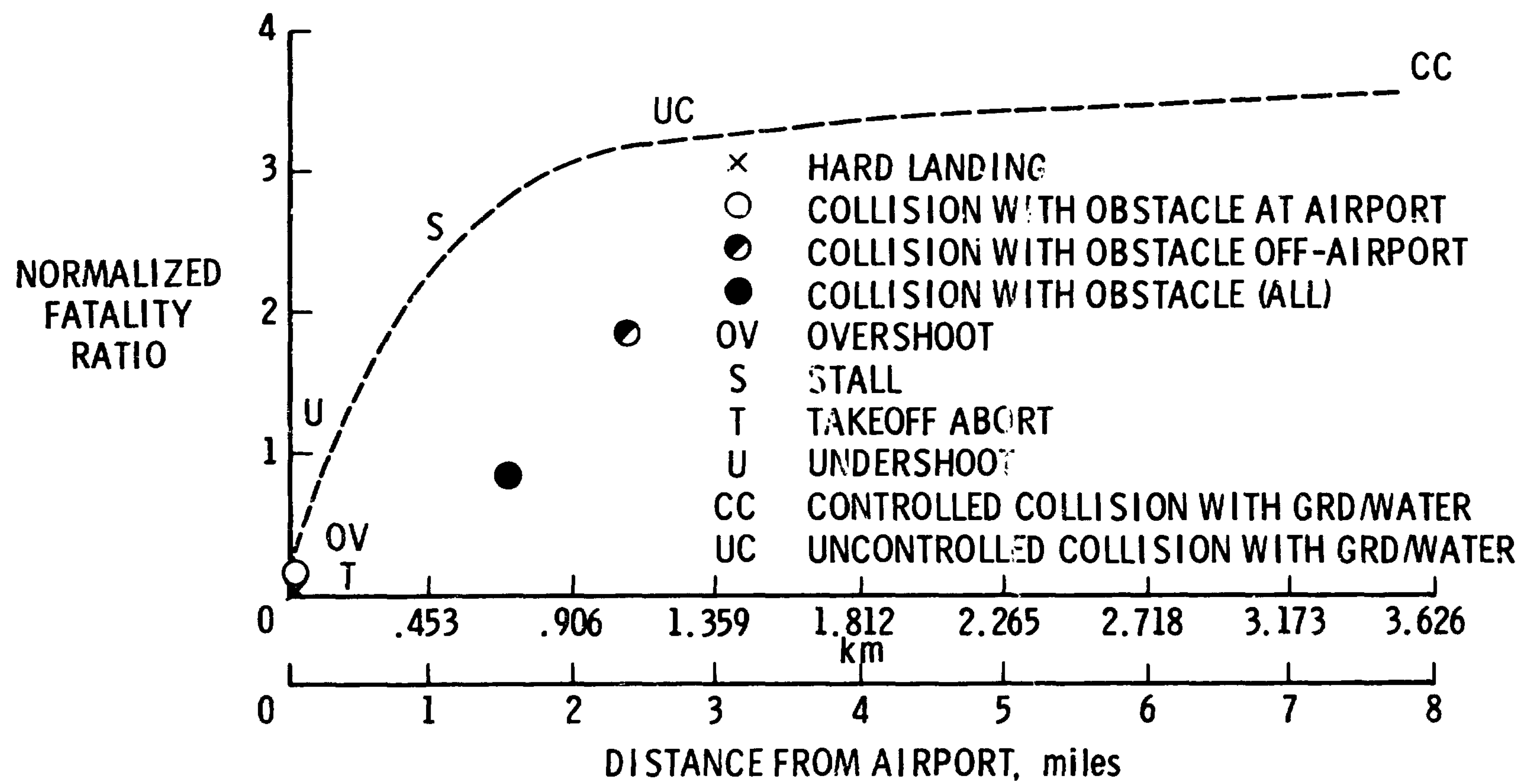


FIGURE 4. - NORMALIZED FATALITY RATIO AS A FUNCTION OF DISTANCE FROM AIRPORT FOR CRASH SCENARIOS

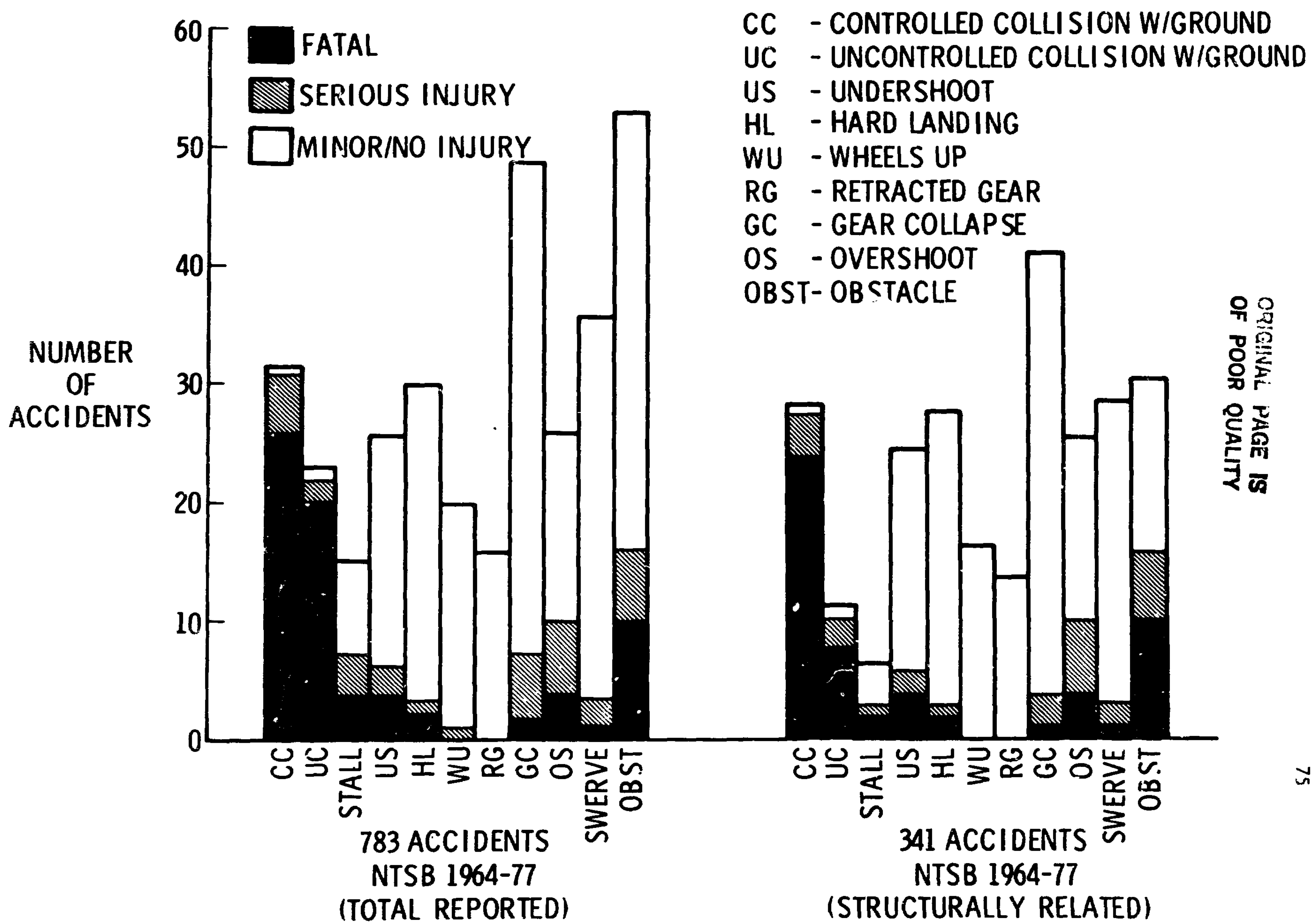


FIGURE 5. - COMPARISON OF NTSB SUMMARIES

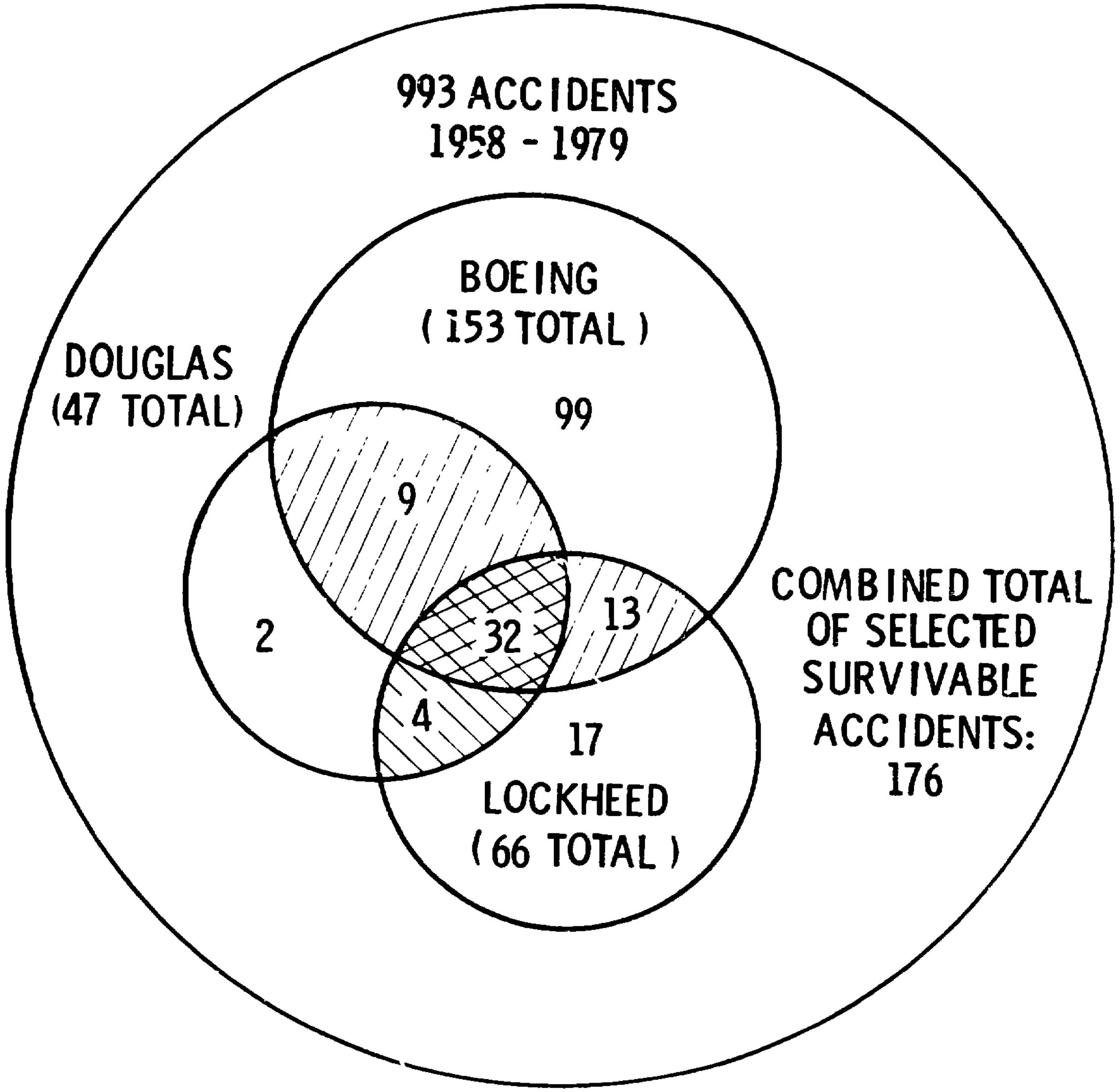


FIGURE 6. - SELECTED ACCIDENT STUDY DATA BASE

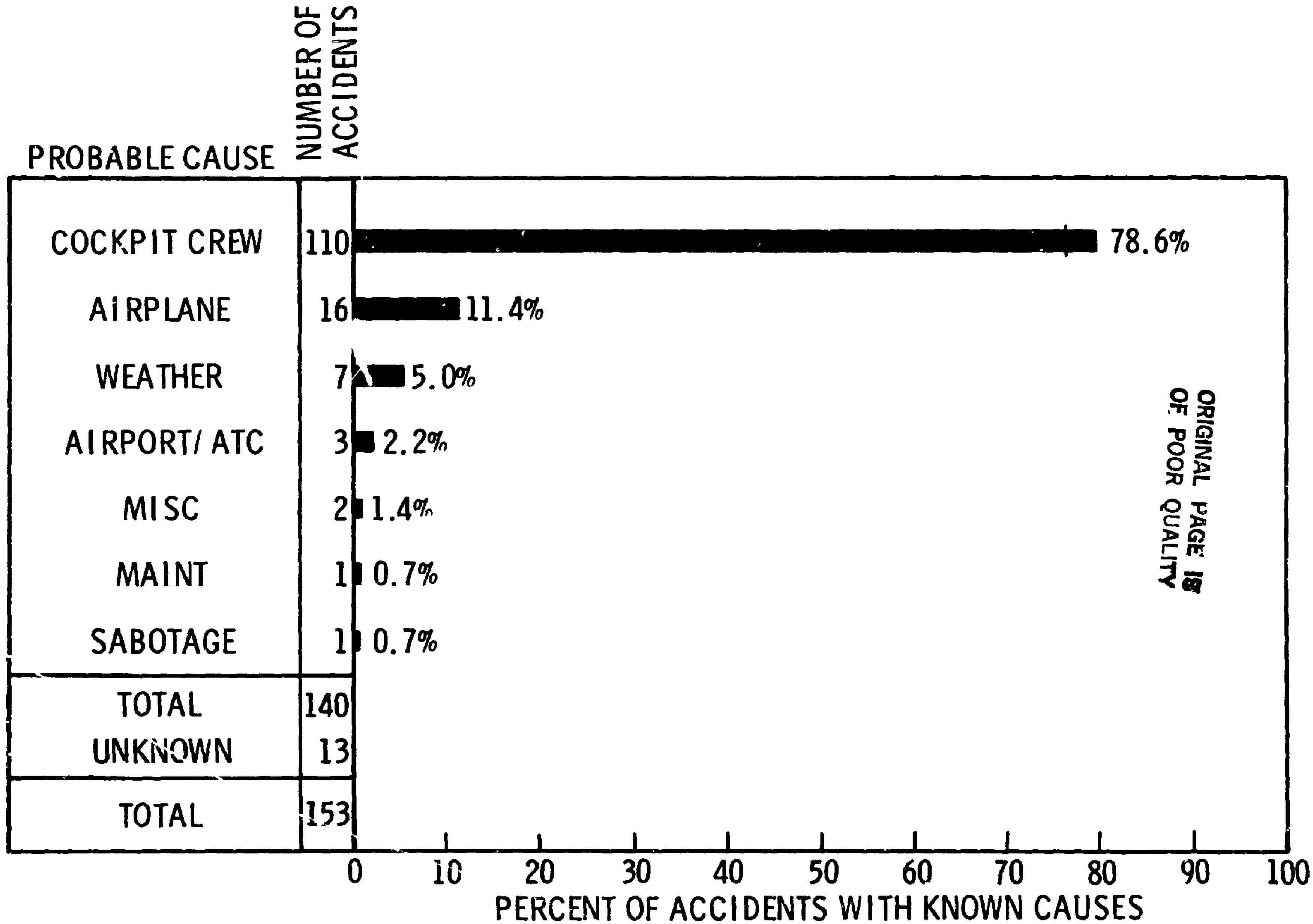
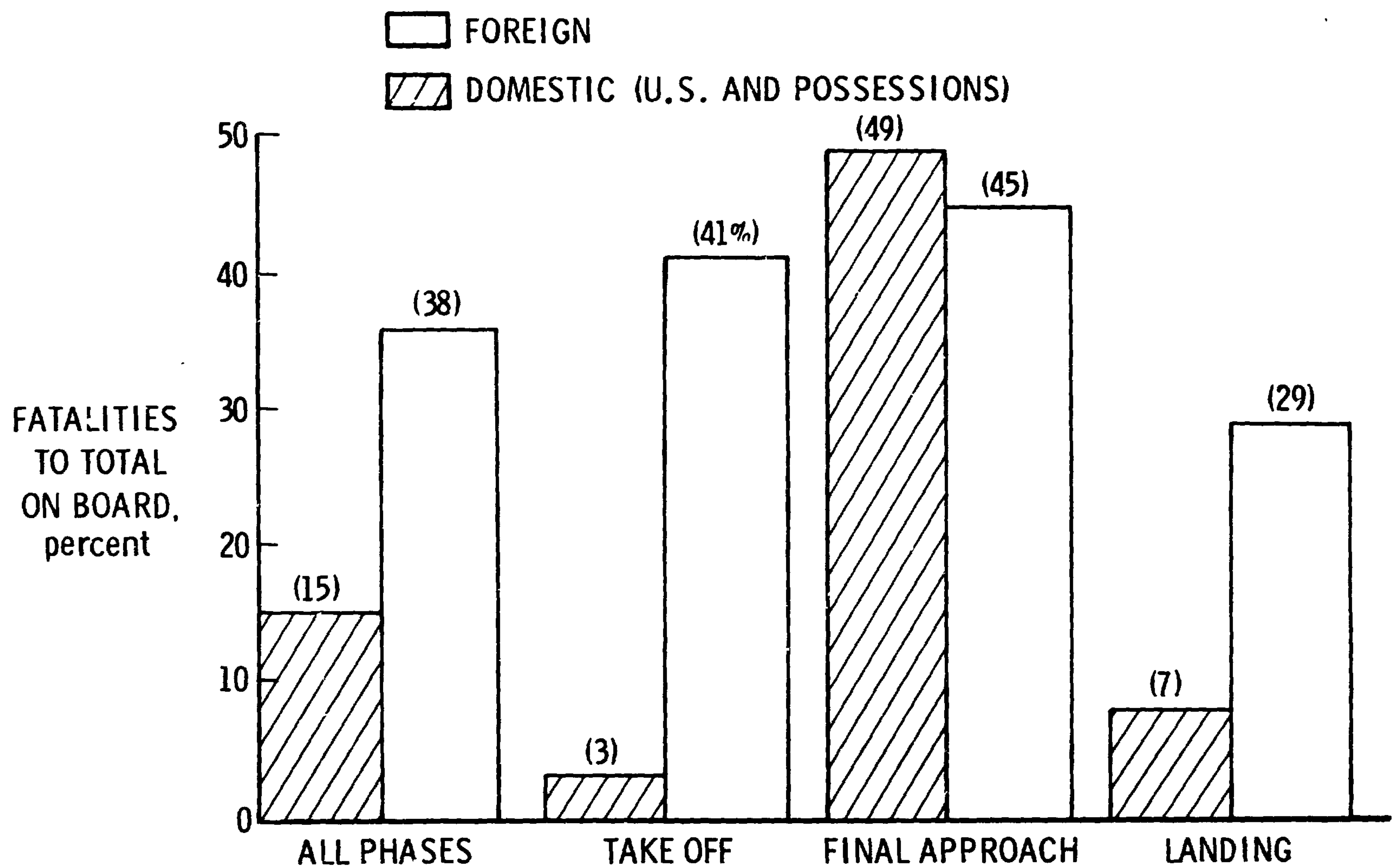
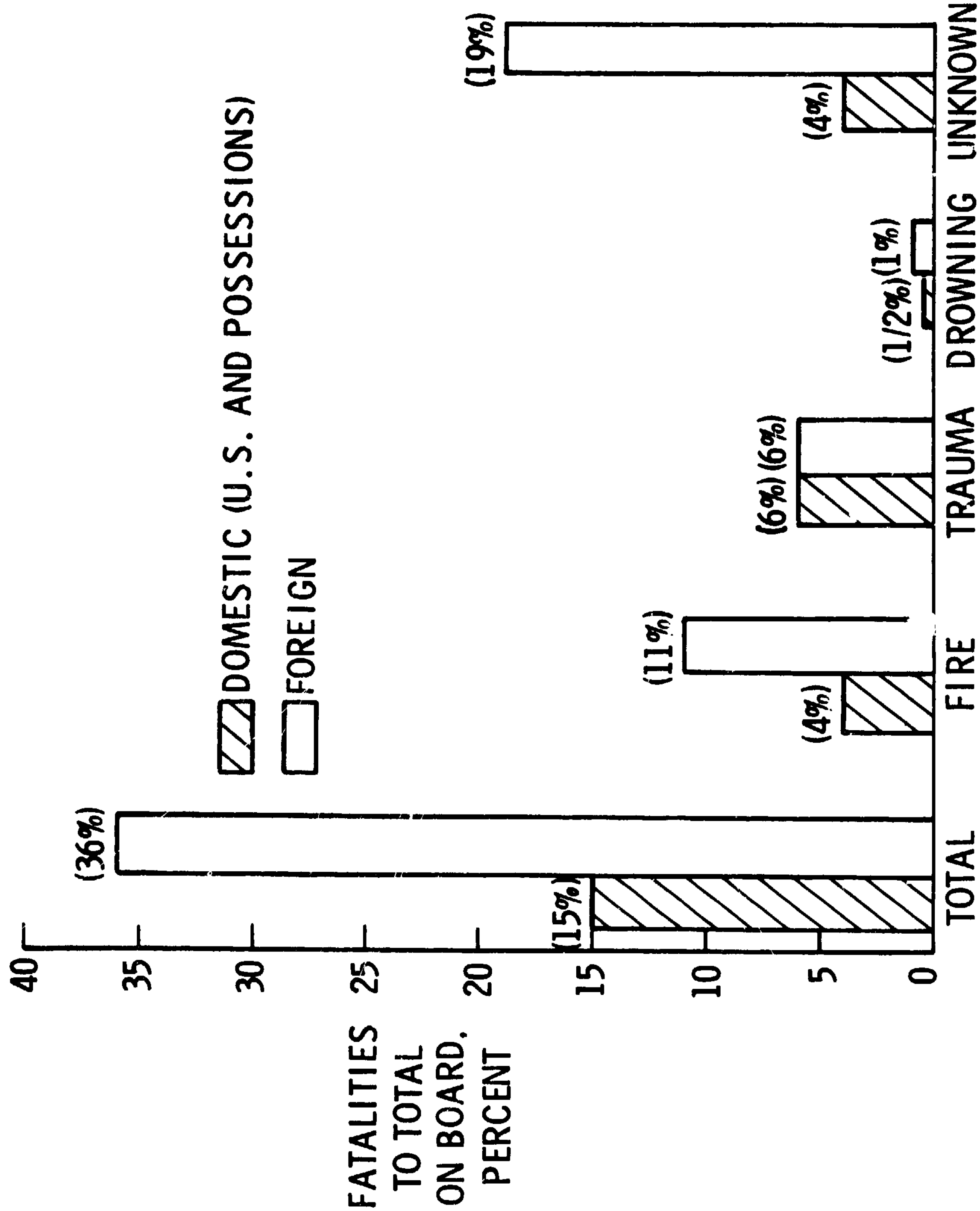


FIGURE 7. - PROBABLE CAUSE OF ACCIDENTS



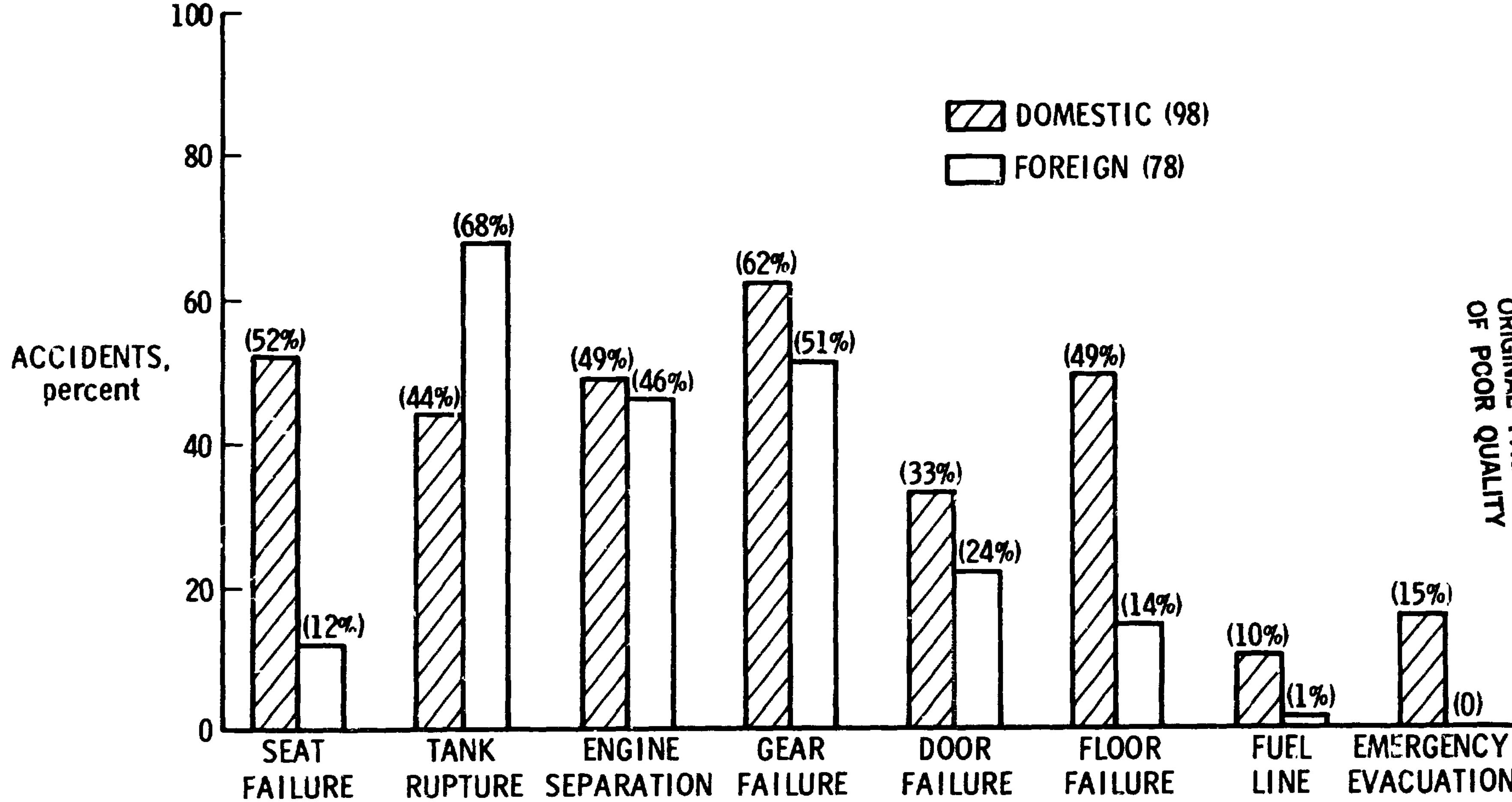
(A) - PHASE OF OPERATION

FIGURE 8. - DOMESTIC VERSUS FOREIGN JET TRANSPORT ACCIDENTS (1959-1979)



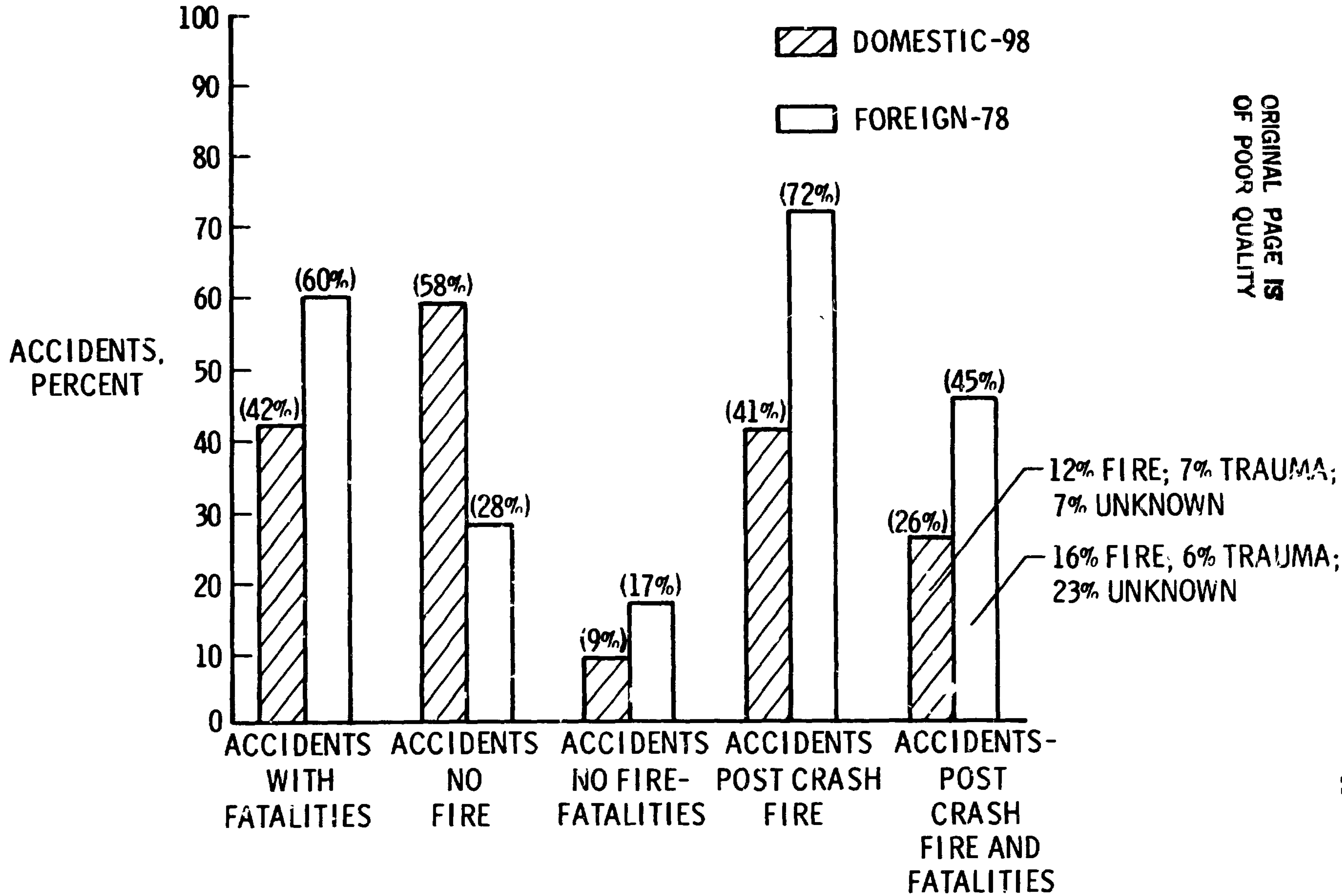
(B) - FATALITY CATEGORY

FIGURE 8. - DOMESTIC VERSUS FOREIGN JET TRANSPORT ACCIDENTS (1959-1979)



(A) - FAILURE MODE (PERCENT OCCURRENCE)

FIGURE 9. - DOMESTIC VERSUS FOREIGN JET TRANSPORT ACCIDENTS (1959-1979)



(B) - ACCIDENTS WITH FIRE AND FATALITIES

FIGURE 9. - DOMESTIC VERSUS FOREIGN JET TRANSPORT ACCIDENTS (1959-1979)

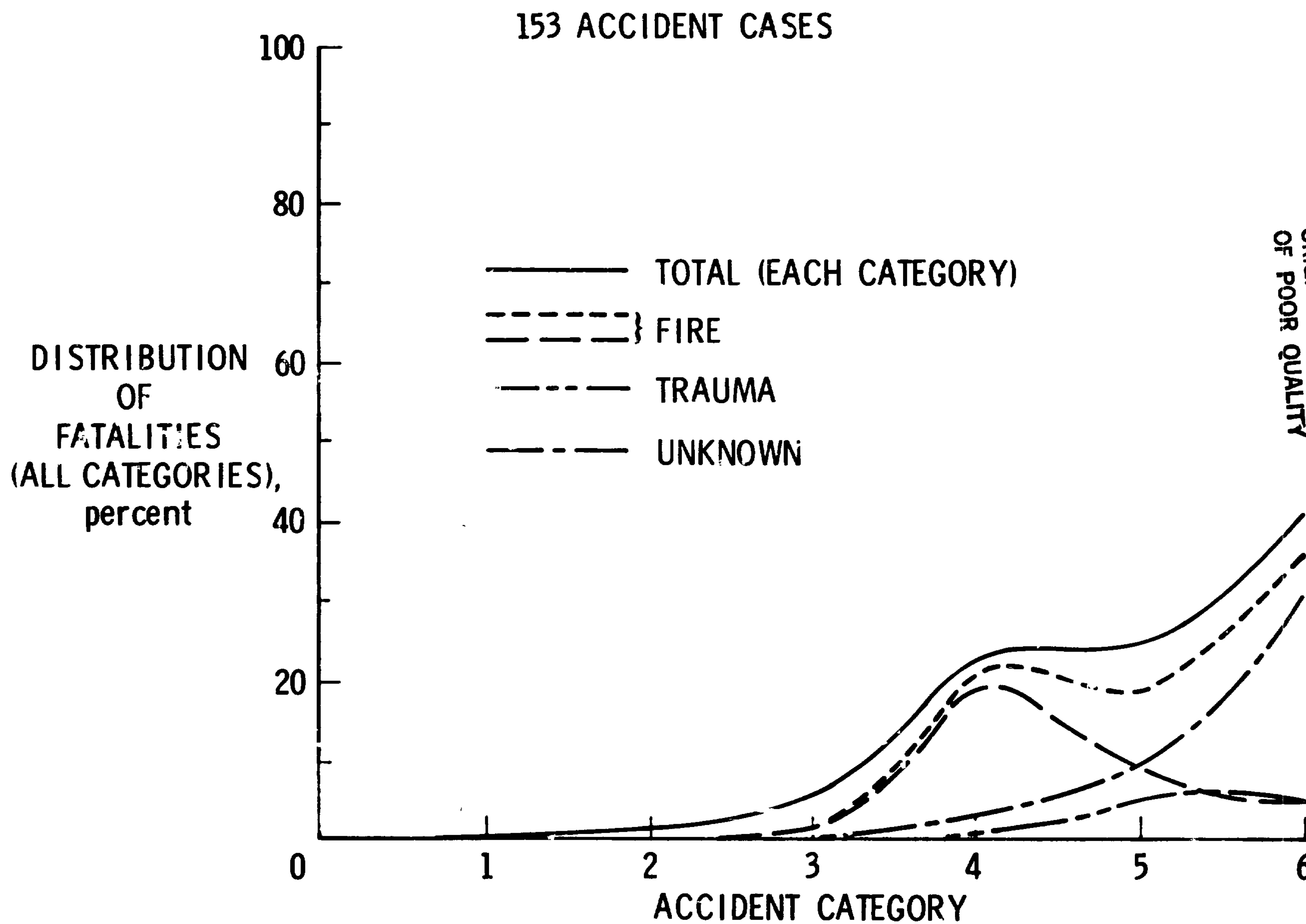


FIGURE 10. - DISTRIBUTION OF FATALITIES AS A FUNCTION OF ACCIDENT CATEGORY

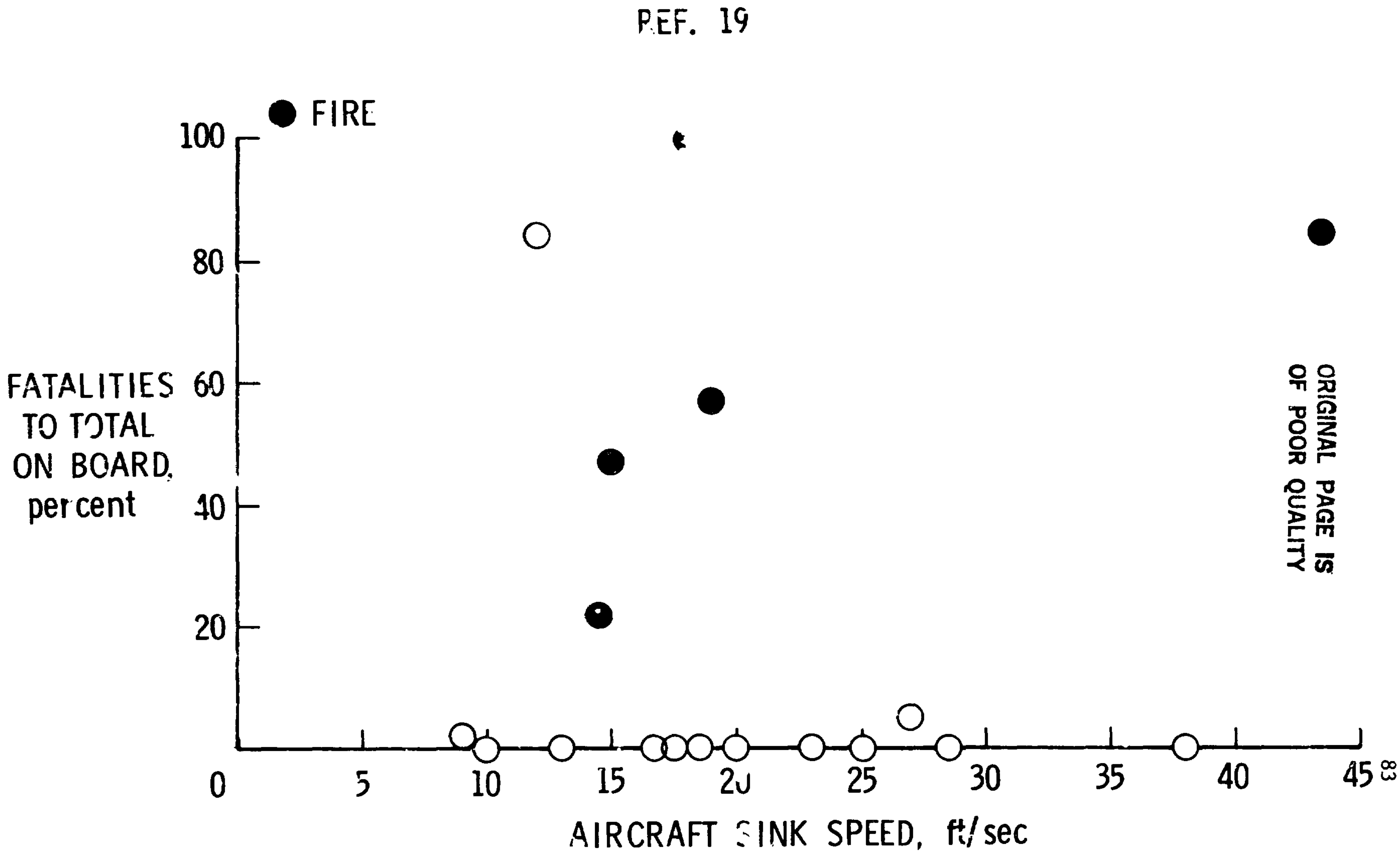


FIGURE 11(A). - FATALITIES AS A FUNCTION OF SINK RATE; REF. 19

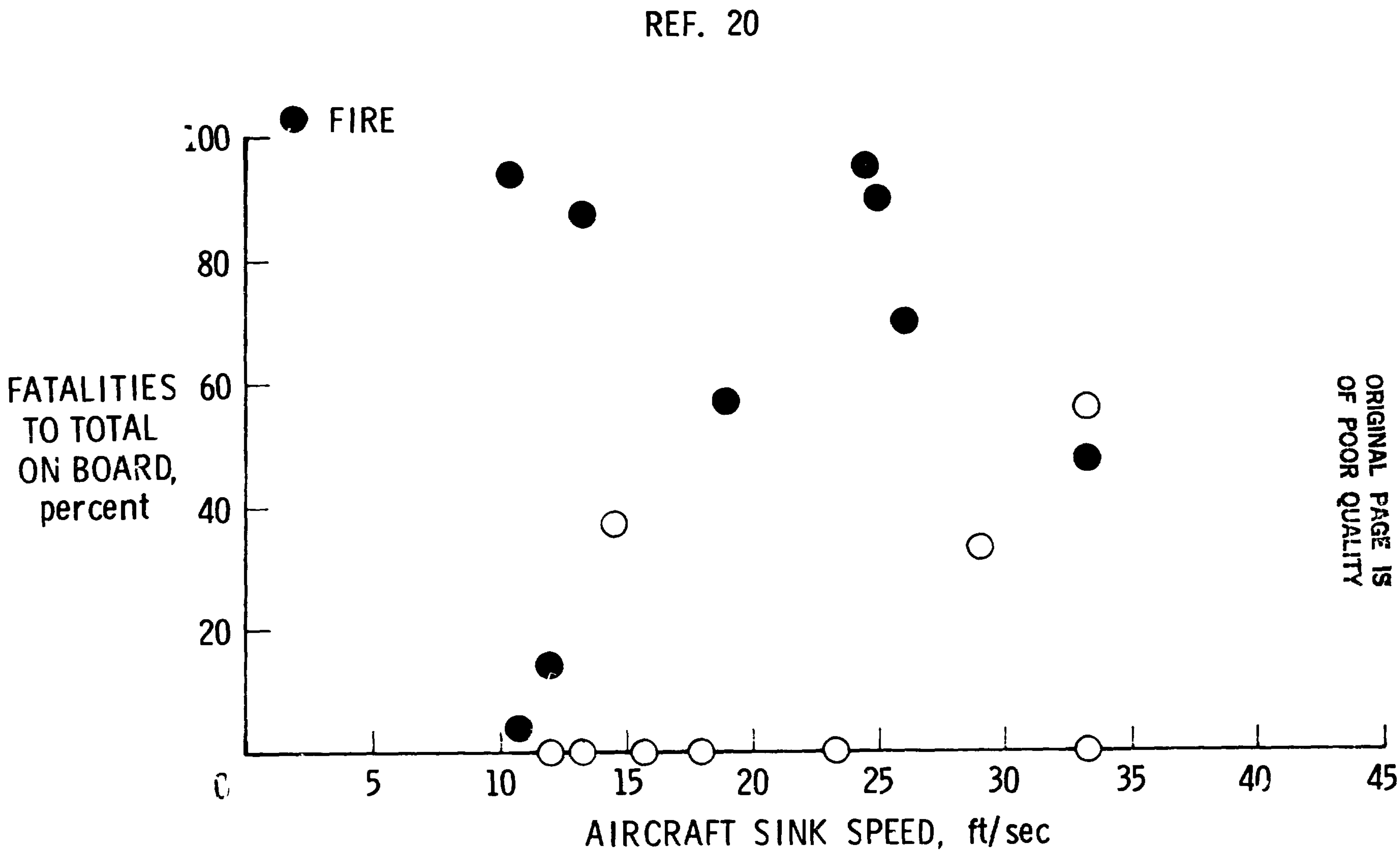


FIGURE 11(B). - FATALITIES AS A FUNCTION OF SINK RATE; REF. 20

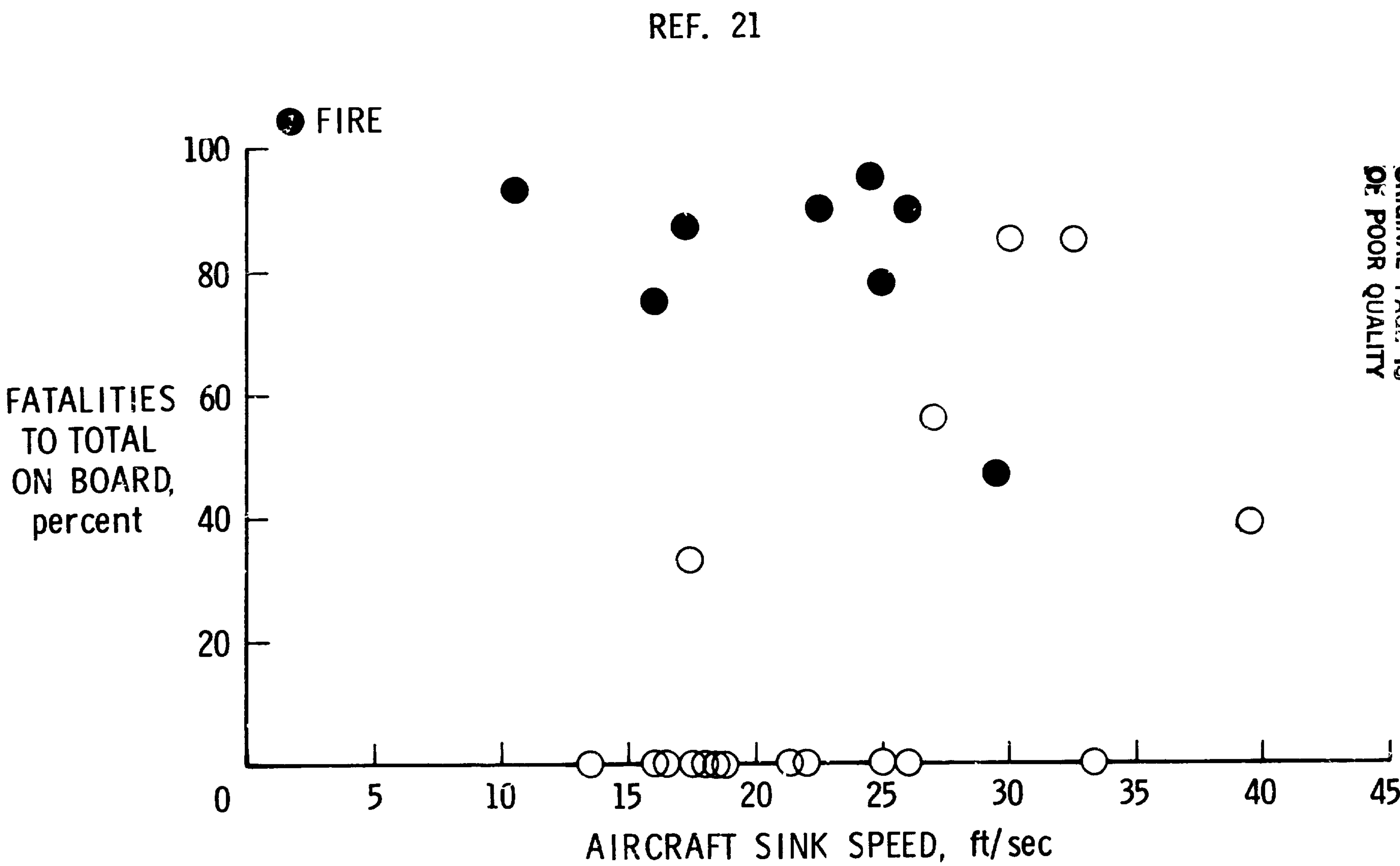


FIGURE 11(C). - FATALITIES AS A FUNCTION OF SINK RATE; REF. 21

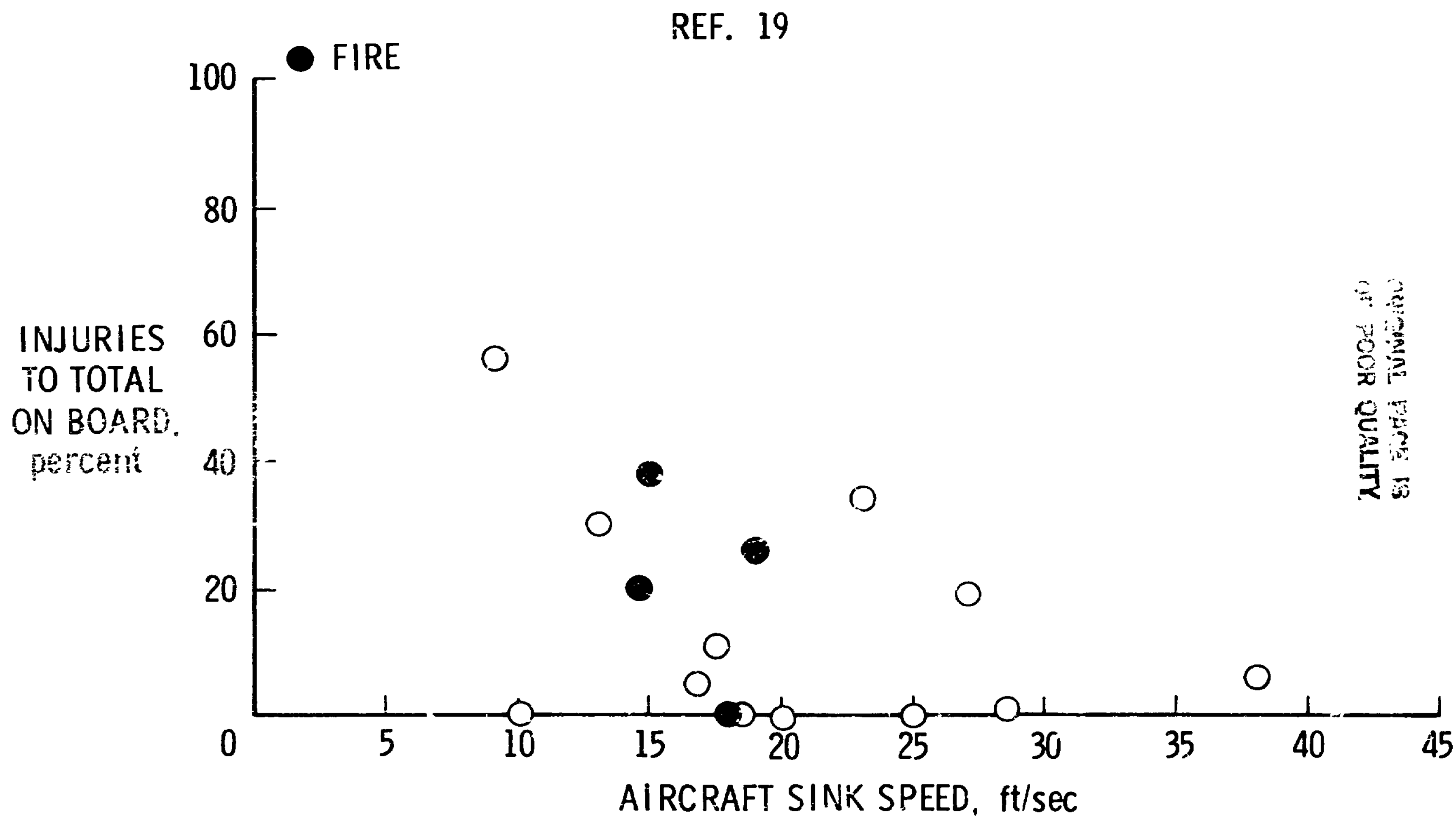


FIGURE 12(A). - INJURIES AS A FUNCTION OF SINK RATE; REF. 19

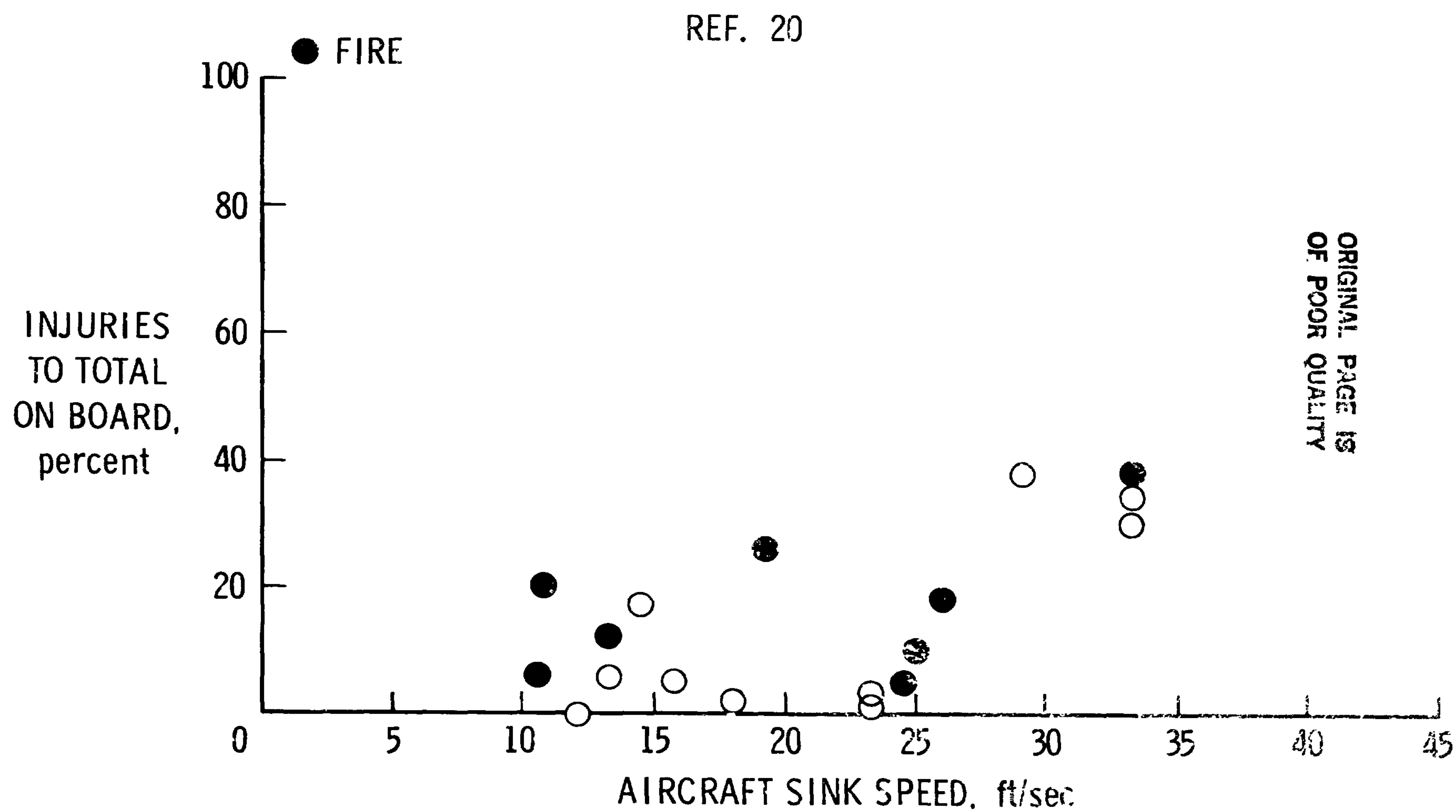


FIGURE 12(B). - INJURIES AS A FUNCTION OF SINK RATE; REF. 20

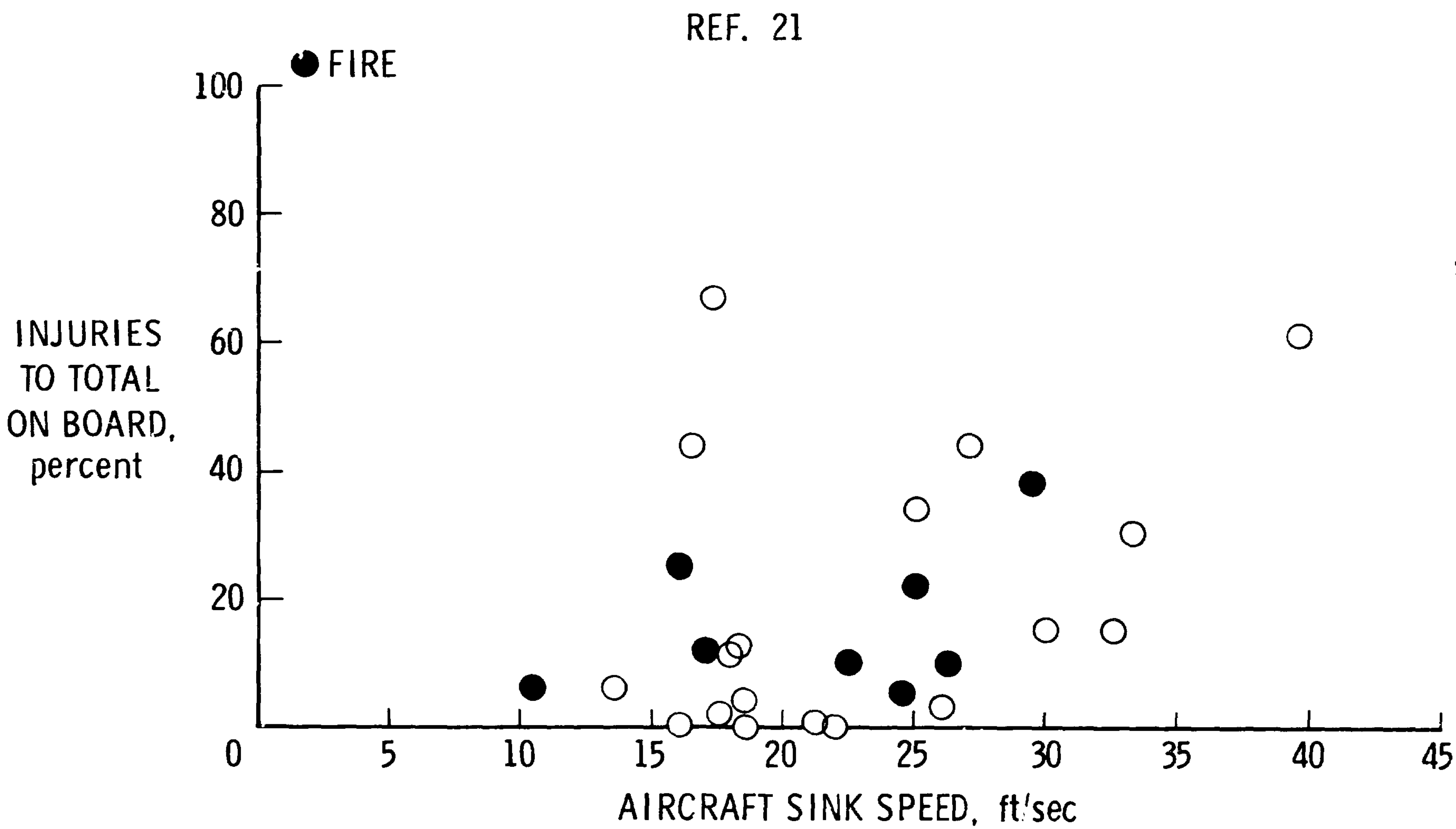


FIGURE 12(C). - INJURIES AS A FUNCTION OF SINK RATE; REF. 21

ORIGINAL PAGE IS OF POOR QUALITY

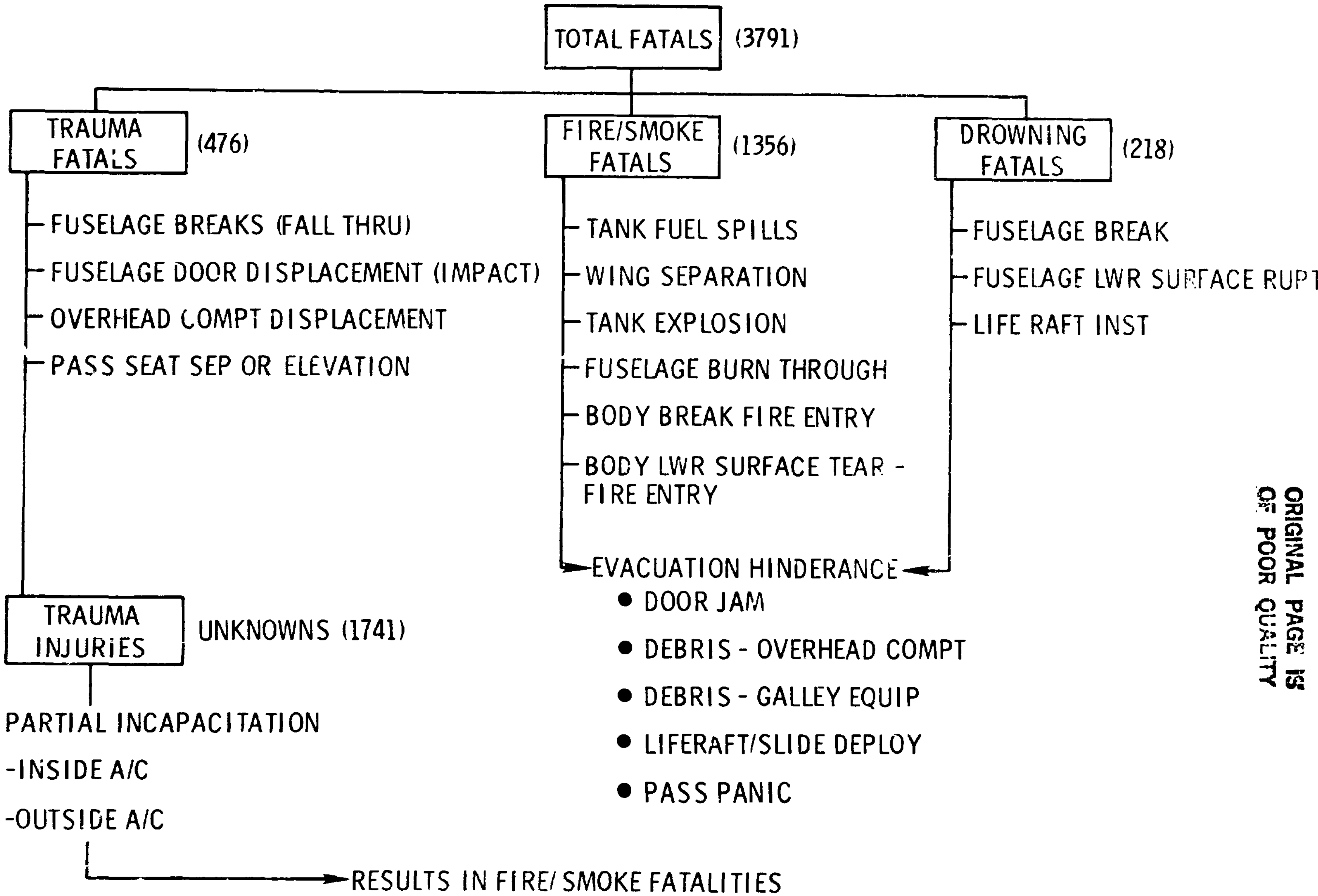


FIGURE 13. - STRUCTURAL FACTORS IN FATALITIES

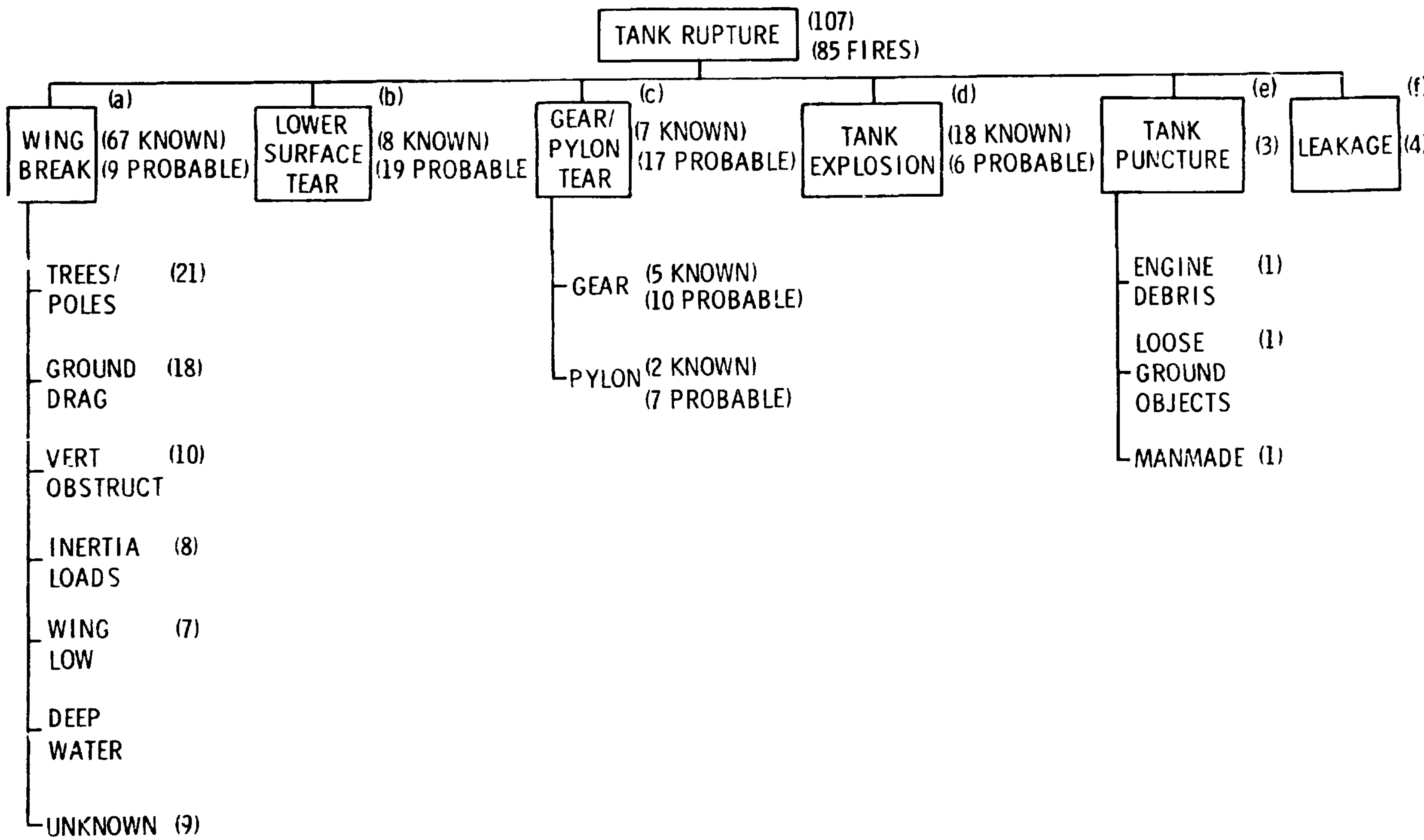


FIGURE A1. - TYPES OF TANK RUPTURE (REF. 19)

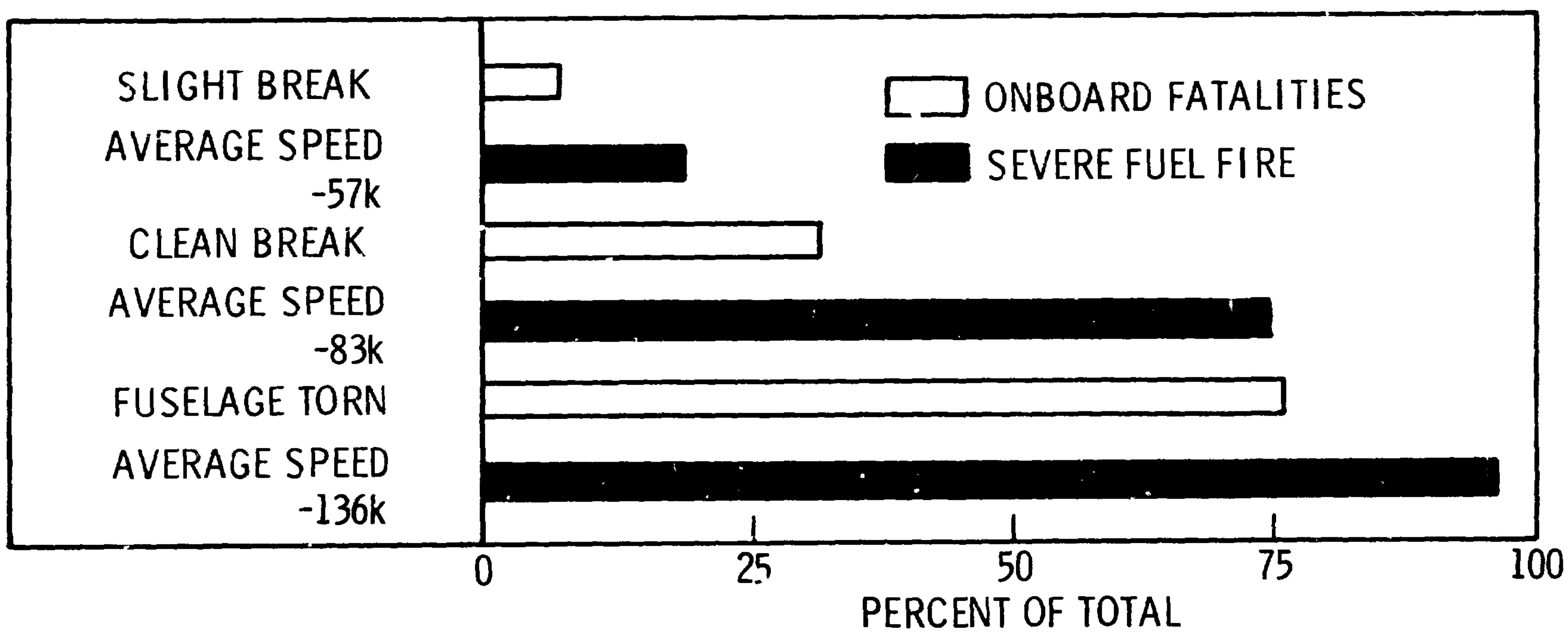


FIGURE A2. - AIRCRAFT SPEED AS RELATED TO ONBOARD FATALITIES

		OCCURRENCES CITED IN 47 ACCIDENTS														
		NUMBER OF CITED OCCURRENCES														
		JAMMING CAUSE				BLOCKAGE CAUSE					COULD NOT BE OPENED			DELAY IN OPENNING	
DOOR-EXIT LOCATION	DOOR OR EXIT POSITION	FRAME DISTORTION	FLOOR LIFT	LATCH MECH.	OUTSIDE OBJECT	GALLEY DEBRIS	INTERIOR & MISC DEBRIS	UNDEFINED	EVAC. SLIDE OR LIFE RAFT	PEOPLE PANIC	NO OTHER EXIT AVAIL ALL FATALS	DIVERT TO OTHER EXITS SOME FATALS	DIVERT TO OTHER EXITS NO FATALS	DIVERT TO OTHER EXITS SOME FATALS	DIVERT TO OTHER EXITS NO FATALS
FWD (39) 47 %	L. ENTRY GALLEY COCKPIT	10 2 	4 2 3	1 1 	2 	 3 	2 3 1		2 1 	1 1 	 1	5 6 	7 6 3	6 	4 1
MID BODY (11) 16 %	FWD WING OVER WING AFT WING	3		1			6	1				4	3		4
AFT (18) 27 %	L. ENTRY TAIL ENTRY GALLEY	4 	2 2 2	 1		 2	2 1 2					6 1 1	1 1 4	 1	1 1 1
TOTAL (68) 100 %		19	15	4	2	5	17	1	3	2	1	23	25	7	12
		40 (59 %)				28 (41 %)					49 (72 %)			19 (28 %)	

FIGURE A3. - DOOR OR EXIT JAMMING AND/OR BLOCKAGE

ORIGINAL PAGE IS OF POOR QUALITY

	TOTAL ON BOARD	TOTAL FATAL-ITIES	% FATAL-ITIES	NUMBER OF ACCIDENTS: LOCATION OF DISPLACEMENT												
				FWD	MID	AFT	SEPAR-ATION	SEAT ELEVA-TION	EXIT DOOR JAM/ BLOCKED	CREW DOOR JAM/ BLOCKED	EGRESS INTER-FERENCE	NOSE GEAR FOLDED AFT	MLG TUMB UNDER BODY	GRD SLIDE	FIRE: SEV-ERE	FIRE: MOD-ERATE
FLOOR DISPLACE. (EXCLUDING FUSELAGE BREAK) TOTAL - 15 (2 FATAL)	1126	18	1.6	12	1		3	7	5	4		8	1	8	4	4
PROBABLE - 1 (1 FATAL)	63	6	9.5			1			1		1					
FLOOR DISPLACE. (INVOLVING FUSELAGE BREAK) TOTAL - 17 (11 FATAL)	1477	368	24.9	10	7	9	13	9	5	2	4	1		14	7	3
PROBABLE - 3	339	132	38.9	2	2	2	1	2	1						2	
FLOOR DISPLACE. DUE TO DEEP WATER ENTRY TOTAL - 4	254	35	13.8	3	1	1	2	3	2		1	1				

FIGURE A4. - PASSENGER/CREW COMPARTMENT FLOOR DISPLACEMENT

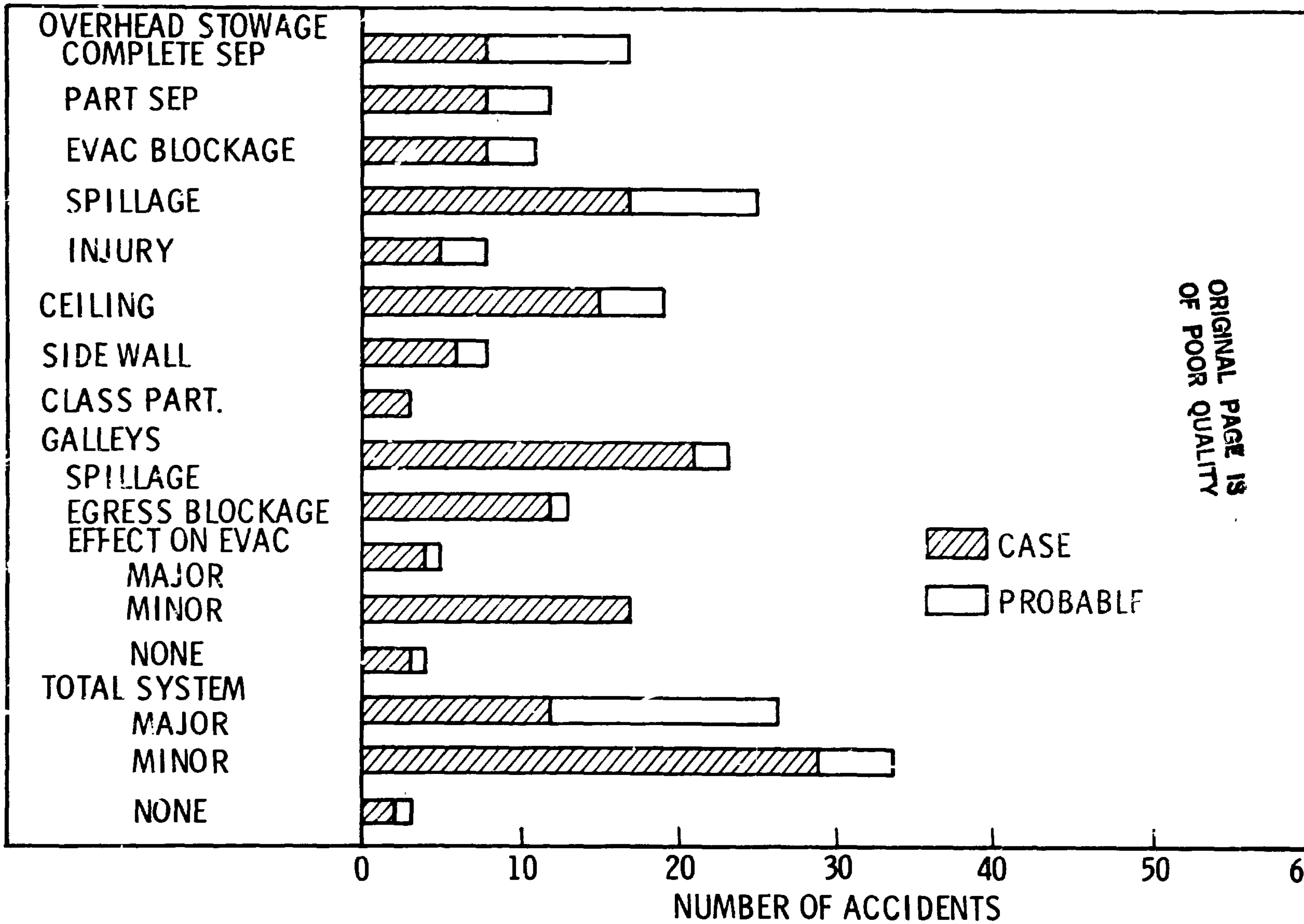


FIGURE A5. - ASSESSMENT OF OVERHEAD STORAGE, CEILING PANELS AND SIDEWALL PANELS

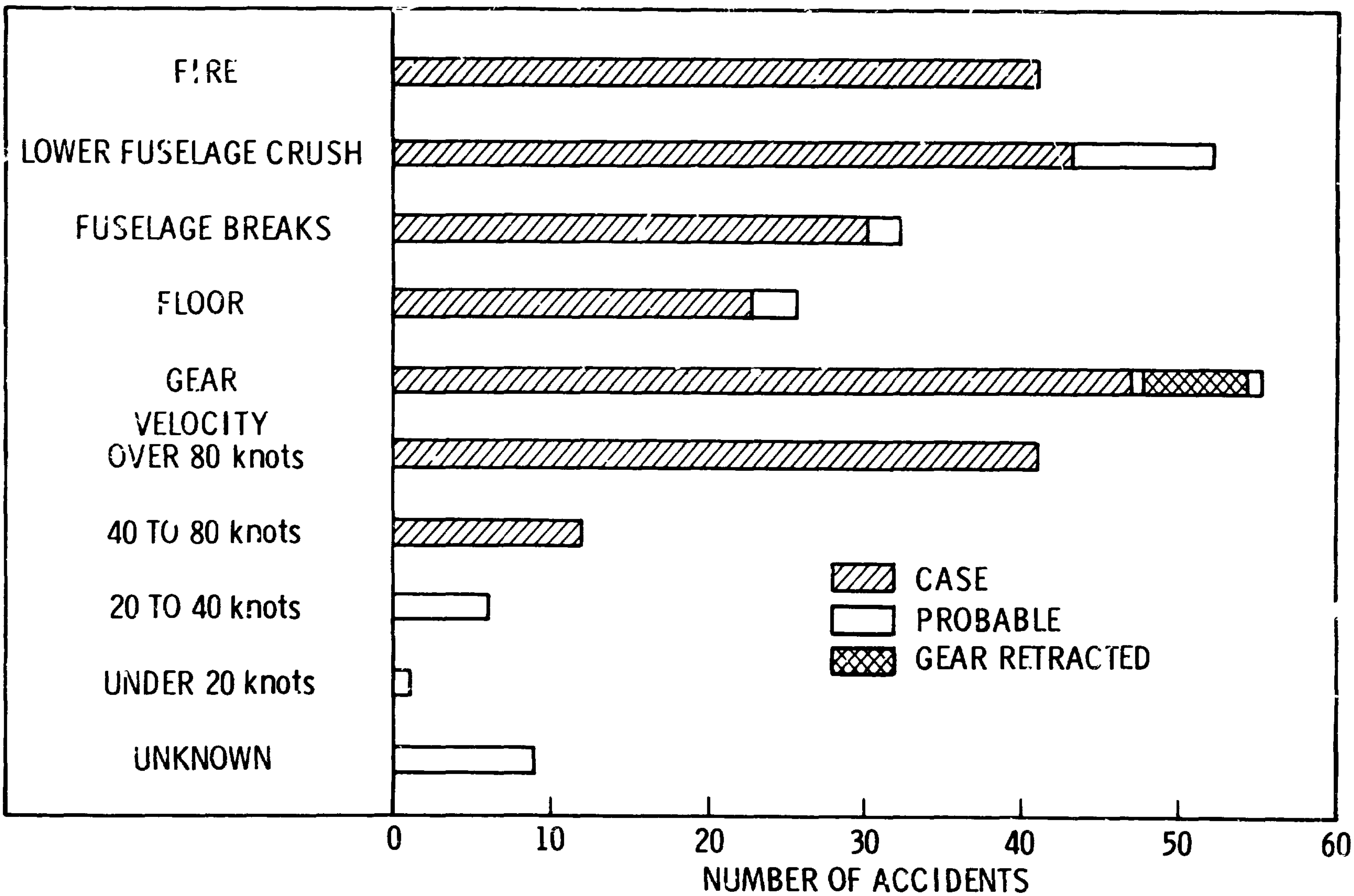


FIGURE A6. - INTERACTION BETWEEN CABIN AND OTHER STRUCTURAL SYSTEMS

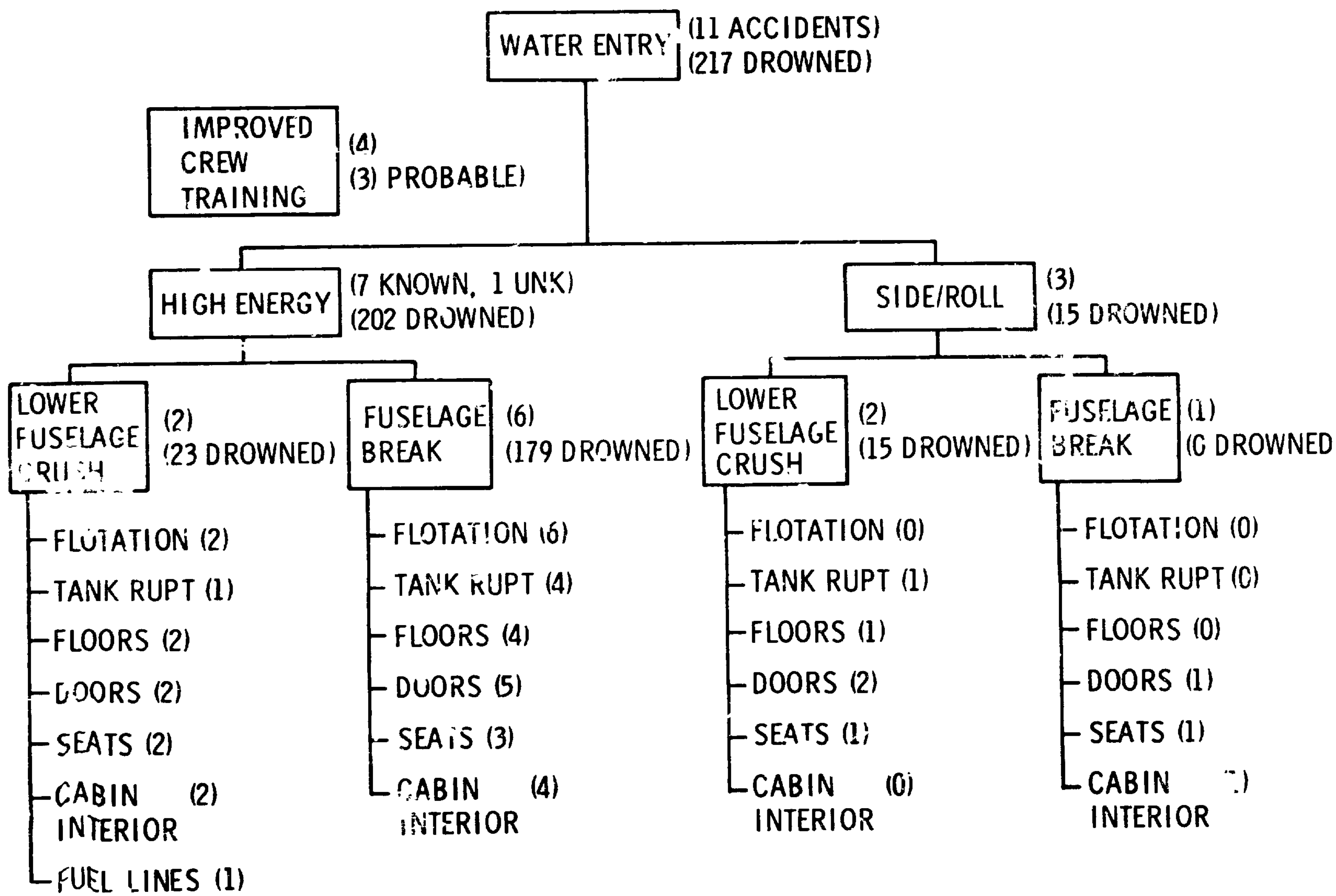


FIGURE A7. - ASSESSMENT OF WATER ENTRY ACCIDENTS

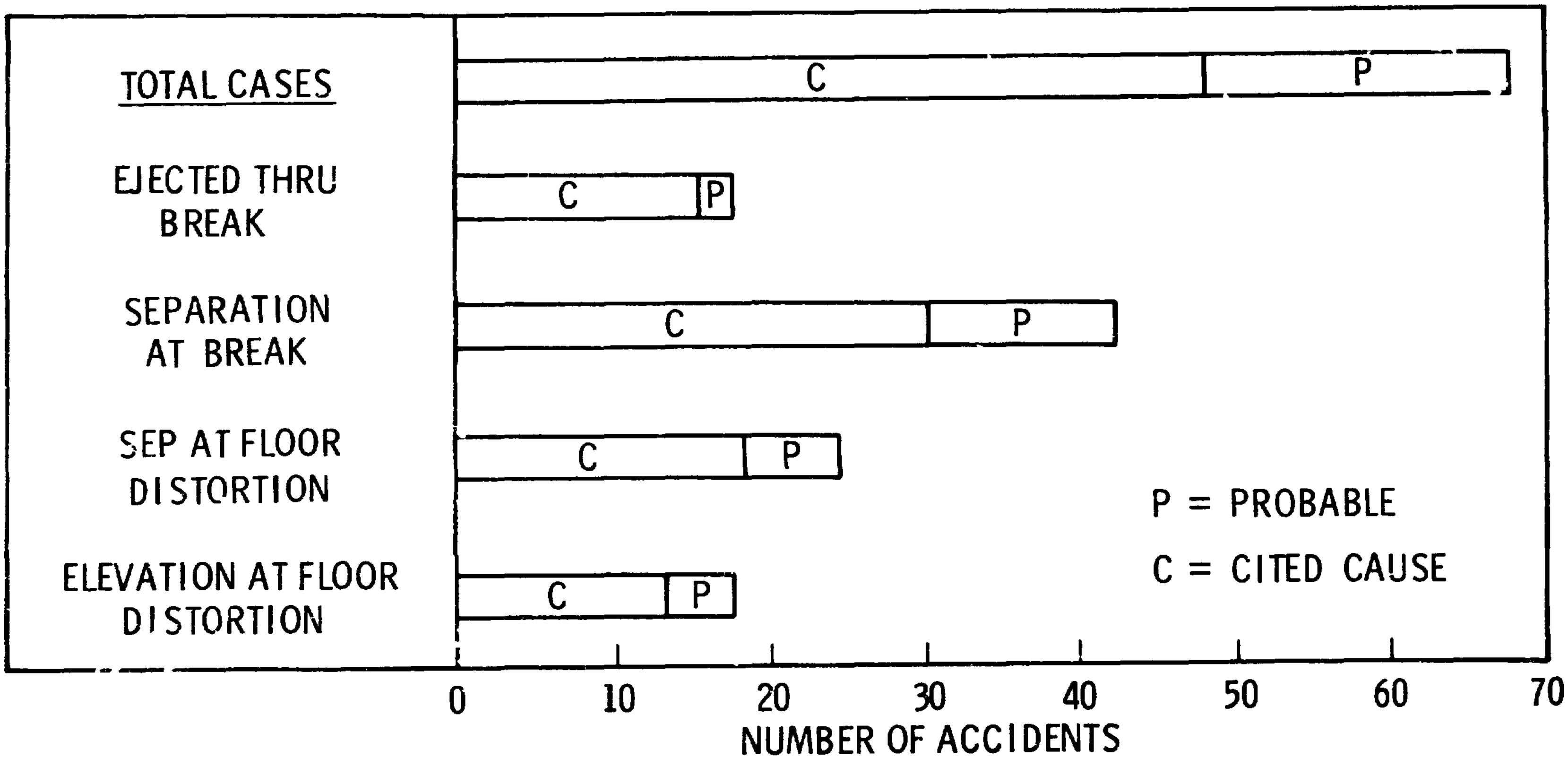


FIGURE A8. - SEAT INTERACTIONS

C-2